EMSWORTH LOCKS AND DAMS
OHIO RIVER
MAJOR REHABILITATION EVALUATION REPORT

TABLE OF CONTENTS

TITLE PAGE

SECTION I - INTRODUCTION..1
1. PROJECT AUTHORIZATIONS.. 1
2. STUDY AUTHORIZATION 1
3. STUDY PURPOSE AND SCOPE.. 1
4. REFERENCES AND PRIOR REPORTS 2
5. PUBLIC INVOLVEMENT 4

SECTION II. DESCRIPTION OF EMSWORTH DAMS........................5
1. EMSWORTH LOCATION AND GENERAL DESCRIPTION.......................... 5
2. CONSTRUCTION HISTORY. 5
3. GENERAL CLIMATOLOGIC AND HYDRAULIC CHARACTERISTICS............ 6
   a. Climate 6
   b. Precipitation.. 6
   c. Gages 6
   d. Flow Characteristics... 6
   e. Extreme Events 6
   f. Pool Characteristics 7
   g. Watershed characteristics.. 7
   h. Ice & Debris 7
   i. Hydraulic Characteristics.. 7
   j. Gate Operations 8
4. EMSWORTH REAL ESTATE - GOVERNMENT OWNED LAND 8
   a. Fee Land 8
   b. Easements.. 8
   c. Licenses... 8
5. MAJOR DAM FEATURES. 8
   a. Service Bridges 11
   b. Locomotive Cranes 12
   c. Bulkhead Cranes 12
   d. Vertical Lift Gates... 13
   e. Vertical Lift Gate Machinery...................................... 14
   f. Electrical Systems and Appurtenant Features 15
      1) Power Source 15
      2) Power Distribution System...................................... 15
      3) Lighting System.. 16
   g. Dam Piers and Abutment 16
   h. Emergency Bulkheads... 17
   i. Stilling Basin/Apron and Scour Protection......................... 17
6. REPAIR HISTORY FOR DAM COMPONENTS (1937-PRESENT) 18
   a. Dam Gates... 21

b. Scour Protection 21
c. Dam Concrete 21
d. Structural Steel Members 22
SECTION III. EMSWORTH POOL 23
1. DESCRIPTION 23
2. USES OF THE POOL 23
a. Commercial Navigation 23
b. Docks, Mooring and Fleeting Areas 25
c. Recreational Facilities 25
d. Water Intakes 26
e. Bridges and Railroad Facilities 26
3. ENVIRONMENTAL SETTING 29
SECTION IV. PROBLEM IDENTIFICATION AND STUDY OBJECTIVES 31
1. PROBLEMS AND OPPORTUNITIES 31
a. Gate Truss Members 31
b. Gate Truck Assemblies 32
c. Dam Gate Operating Machinery 34
d. Scour Protection 38
e. Dam Concrete 39
f. Service Bridges 40
g. Summary 41
2. STUDY OBJECTIVES AND CONSTRAINTS 41
SECTION V. PLAN FORMULATION 43
1. WITHOUT PROJECT CONDITION 43
a. Fix-As-Fails 44
b. Scheduled Repair 45
c. Advanced Maintenance 46
d. Hybrid Repair/Maintenance 47
2. REHABILITATION ALTERNATIVES 47
a. Immediate Rehabilitation 47
b. Scheduled Rehabilitation. 47
SECTION VI. ENGINEERING ANALYSIS 49
1. METHODS OF ENGINEERING ANALYSES 49
2. COMPONENTS ANALYZED WITH RELIABILITY TECHNIQUES 49
a. Gate Trusses 50
b. Gate Truck Assemblies 51
c. Gate Operating System 52
3. COMPONENTS CONSIDERED WITHOUT FORMAL RELIABILITY TECHNIQUES 53
a. Scour Protection 53
b. Dam Concrete 54
c. Service Bridge 54
4. EVENT TREES 54
5. BANK STABILIZATION CONCERNS 55
6. HAZARD RATES AND FAILURE PROBABILITY RESULTS 56
a. Gate Trusses 56

b. Gate Truck Assemblies 57
c. Dam Gate Operating Systems 57
d. Chains 58
e. Scour Protection 58
SECTION VII. ECONOMIC ANALYSIS........ 61
1. GENERAL 61
a. Models 61
b. Methodology 61
2. EVALUATION OF ALTERNATIVES 64
a. Without Project Condition 64
b. With Project Condition 66
1) Immediate Rehabilitation 66
2) Deferred Rehabilitation 67
c. Economically Preferred Alternative 68
d. Summary Table 70
3. INCREMENTAL AND TIMING ANALYSIS 71
a. Incremental Justification of Each Component 71
b. Timing Analysis for Deferred Repairs 71
4. SCREENING AND FINAL BENEFITS AND COSTS 72
SECTION VIII. OTHER CONSIDERATIONS 75
1. COMPONENTS NOT ANALYZED WITH RELIABILITY 75
a. Service Bridges 75
b. Dam Concrete 75
2. ENVIRONMENTAL AND CULTURAL RESOURCE CONSIDERATIONS 76
3. REAL ESTATE CONSIDERATIONS 77
SECTION IX. CONCLUSIONS AND RECOMMENDATIONS........ 79
1. CONCLUSIONS 79
2. RECOMMENDATION 83
3. MAJOR REHABILITATION CLASSIFICATION 83
4. DESCRIPTION OF RECOMMENDED WORK 83
a. Project Features 83
1) Dam Lift Gates 83
2) Dam Lift Gate Operating Machinery 84
3) Scour Protection 84
4) Service Bridge Deck 85
5) Crane Rail System 85
6) Steel Bridge Members 85
b. Timing 85
c. Real Estate 85
d. Federal Interest 86
SECTION X. ADMINISTRATIVE CONSIDERATIONS 87
1. PROJECT COST ESTIMATE 87
2. PROJECT COST SHARING 87
3. PROJECT MANAGEMENT PLAN 87
4. EFFORTS DURING PRECONSTRUCTION ENGINEERING AND DESIGN 87

DRAFT ENVIRONMENTAL ASSESSMENT

LIST OF TABLES

TITLE PAGE

Table I-1 Applicable Corps Regulations and Prior Reports 3
Table II-1 Maintenance History Of Gated Dams... 19
Table II-2 Major Rehabilitation Activities.. 20
Table III-1 Historic and Projected Traffic 24
Table III-2 Projected Recreation Days... 25
Table III-3 Historic Emsworth L/D Recreation Traffic... 25
Table III-4 Commercial Docks, Mooring, & Fleeting Areas.. 27
Table III-5 Existing Recreation Facilities Within Emsworth Pool...................................... 27
Table III-6- Water Intakes and Wells Operating in Emsworth Pool 29
Table IV-1 Truck Assembly Renovations 33
Table VI-1 Hazard Rates for Dam Components... 56
Table VI-2 Dam Gate Operating Failures.. 58
Table VI-3 Scour Protection, Stilling Basin/Apron and Gated Dam Piers.......................... 59
Table VII-1 - Economics of Alternative leading to Without Project Condition.................. 66
Table VII-2 - Economics of Immediate Rehabilitation... 67
Table VII-3 - Deferred Rehabilitation and Repairs - Average Annual Costs...................... 67
Table VII-4 - Costs of Disruption - With and Without Conditions 68
Table VII-5 - OMRR&R Costs of With and Without Project Alternatives......................... 69
Table VII-6 - Economics of With and Without Project Conditions 69
Table VII-7 - Economics of All Alternatives... 70
Table VII-8 - Incremental Analysis 71
Table VII-9 - Deferred Repairs.. 71
Table VII-10 - Comparison of Preliminary and M-CACES Costs 72
Table VII-11 - Annualized Costs and Benefits.. 72
Table IX-1 Summary Analysis of Plans 80

LIST OF FIGURES

II-1 - Emsworth Locks and Dams
II-2 - Emsworth Pool

LIST OF PHOTOS

II-1 - Main Channel Service Bridge
II-2 - Main Channel Locomotive Crane
II-3 - Vertical Lift Gate Truss Assembly
II-4 - Vertical Lift Gate Machinery
II-5 - Programmable Control Panel
II-6 - Main Channel Emergency Bulkhead
II-7 - Stone Blanket Material

III-1 - Corroded Dam Gate Truss Members
III-2 - Wheel Truck Out of Track At Pier #2
III-3 - Broken Chain Resulting From Dropped Gate, February 1988
III-4 - Damaged Lower Gate Truck Assembly Resulting From Dropped Gate, February 1988

APPENDICES

APPENDIX A - GENERAL ENGINEERING AND RELIABILITY

APPENDIX B - ECONOMIC ANALYSIS

APPENDIX C - MCACES COST ESTIMATE

APPENDIX D - PROJECT MANAGEMENT PLAN

APPENDIX E - FULLY FUNDED PROJECT COSTS

APPENDIX F - INDEPENDENT TECHNICAL REVIEW

APPENDIX G - REAL ESTATE PLAN

EMSWORTH LOCKS AND DAMS MAJOR REHABILITATION EVALUATION REPORT

Ohio River
Pittsburgh, Pennsylvania

SECTION I - INTRODUCTION

1. PROJECT AUTHORIZATIONS.

The original Emsworth Locks and Dams were authorized under the authority of the River and Harbor Act of 18 July 1918, which stated "That the Secretary of War is hereby authorized to modify the project for the improvement of the Ohio River in accordance with the report submitted in House Document 1695, 64th Congress, 2nd Session." The House document recommended the replacement of original Ohio River Lock and wicket Dam Nos. 1 and 2 by the Emsworth Locks and Dams project, comprising a fixed crest dam separated by Neville Island into two sections and dual locks.

Modernization of both the main channel and back channel dams took place during 1935 to 1938 and involved the partial removal of the original fixed crest dams and the construction of gated dams equipped with vertical lift gates. These improvements were authorized under the Emergency Relief Appropriation Act dated 8 April 1935.

2. STUDY AUTHORIZATION

The on-going major rehabilitation of locks and dams nationwide was authorized under the Water Resources Development Acts (WRDAs) of 1986 and 1992. This Major Rehabilitation Evaluation Report (RER) for Emsworth Dams, on the Ohio River, was prepared under these authorities. In this report, any work under WRDA 1986 and 1992 authorities (both past or future-recommended) are designated as "Major Rehabilitation".

3. STUDY PURPOSE AND SCOPE

The purpose of this Major Rehabilitation Evaluation Study is to identify the most cost effective and efficient way to ensure safe and reliable operation of Emsworth Dam for a 50-year study period. The initial year represents the first year that a rehabilitation project could be operational, and the end date is fifty years afterwards. This report describes the general problems caused by age, deterioration, corrosion, and fatigue of critical components of Emsworth Dams and recommends remedial actions.

Specific tasks required to accomplish the study purpose include:

- Identification of components of Emsworth Dams that are essential for the safe operation of gates and which are of questionable reliability.
- Assessment of the existing condition (current state) of these components, any problems already being encountered, and their consequences.
- Evaluation of future likelihood's of failure and associated consequences inherent with a continual patch-work strategy. This involves identification of all failure modes for critical components and estimation of the associated probabilities of failure.
- Formulation of measures to address the problems and avoid catastrophic failures of dam components or lessen the severity of consequences of such failures. Potential work items include major repairs and replacements of individual components.
- Economic analyses of alternative repair/replacement strategies for all critical components to determine the optimal timing of such work, if any. The Major Rehabilitation alternatives would involve "bundling" many or all measures into one work package at the opportune point of time.

The Major Rehabilitation work recommended in this report will avoid catastrophic failure of the dam, which might hinder navigation and cause accidents or even injuries during the sudden loss of pool. Moreover, it will be shown to be more economic than performing such work only when required by failure and other alternative maintenance strategies.

This report will focus entirely on the condition and restoration of the dam at Emsworth, and will not consider modifications to the lock chambers adjacent to the main channel dam. Although there are significant concerns with lock components, any work requirements must be evaluated in a lock modernization study that considers the added benefits of larger locks, which is outside the scope of rehabilitation evaluation reports. Preliminary studies of Emsworth L/Ds performed as part of the on-going Ohio River Main Stem System Study (ORMSS) indicate that the most promising lock improvement plans would involve construction of one or two larger locks at the existing site. This could require the removal of one gate bay that is recommended for rehabilitation in this RER. The likely construction of larger locks at the existing site is based in part on stability studies of Emsworth Dams that show that, structurally, these two dams can survive well into the 21st century. The gate and gate operating system improvements would even be able to accommodate certain long-term ORMSS navigation alternatives that involve lowering the tailwater, as would occur if Dashields would be removed. However, reconstruction of the scour protection could be affected by the lowering of the downstream pool. The effect would be modeled during the detailed design phase, if rehabilitation is approved. It is expected that the plans for the locks will be known by that time, so that modification to the designs of the scour protection could be made, if necessary, prior to construction.

4. REFERENCES AND PRIOR REPORTS

Study and report processes for this RER follow a number of Corps regulations (Engineering Regulations, or ER's, and Engineering Pamphlets, or EP's) concerning planning requirements in general and for Major Rehabilitation studies in particular. Maximum use of prior reports and assessments of Emsworth Dams was made. Table I-1 lists pertinent significant references and summarizes their application. Many of these references are also described in later sections.

Table I-1 Applicable Corps Regulations and Prior Reports

Document Title	Date	Summary of Use
Corps Regulations		
Planning Guidance (Engineering Regulation {ER} 1105-2-100)	22 April 2000	General Study Activities including Plan Formulation, Economic Evaluations, and Environmental Documentation
NEPA Reg (ER 200-2-2)	4 March 1988	Environmental Assessment Preparation and Coordination
Major Rehabilitation Evaluation Report Guidance (Engineering Pamphlet {EP} 1130-2-500)	27 December 1996	General Evaluation and Reporting Requirements for Major Rehabilitation Evaluation Reports
Reliability Assessment of Navigation Structures (Engineering Technical Letter {ETL} 1110-2-532)	May 1992	Structural analyses of gate components.
Engineering Technical Letter (ETL) 1110-2-549, Engineering and Design, Reliability Analysis of Navigational Lock and Dam Mechanical and Electrical Equipment	30 November 1997	Analysis of mechanical and electrical components of the dam operating system
Prior Reports		
Emsworth Periodic Inspections	1996 and 2001 (latest PI's)	General Condition Assessments of Dam Components
Upper Ohio River Dotson/Stilson	January 2001	General Condition Assessments of Dam Components
Tri-State Reliability	December 2000	Truss Reliability Analysis
Tri-State Service Bridge Inspections	March 2001	General Condition Assessment of Service Bridge

5. PUBLIC INVOLVEMENT

This study is referenced on the Pittsburgh District Web Internet page, Operations and Readiness Division, under "Operations and Maintenance". District representatives will also announce the study and anticipated study recommendations at the March 2001 meeting of the Pittsburgh Waterways Association.

SECTION II. DESCRIPTION OF EMSWORTH DAMS

This section describes the location and physical characteristics and functions of Emsworth Locks and Dams facilities, with emphasis on the Main and Back Channel Dam components. The construction history and remedial work performed on dam components are presented. This work history is useful in that it provides some basis for expectations of future work on components.

1. EMSWORTH LOCATION AND GENERAL DESCRIPTION.

The Emsworth Project, located on the Ohio River, consists of 2 dam structures, one on each side of Neville Island, and 2 parallel lock chambers situated on the right descending bank. The land chamber is dimension 110'x600', and the adjacent river chamber is 56'x360'. The main channel, or Emsworth side of the dam, is 6.2 miles below the confluence of the Allegheny and Monongahela rivers at Pittsburgh, Pennsylvania. The back channel dam is at river mile 6.8. Figure II-1 presents Emsworth Locks and Dams in plan view. The Emsworth pool extends upriver to Allegheny River Lock and Dam 2 at river mile 6.7 and to Braddock Lock and Dam at Monongahela River Mile 11.2. The Emsworth pool is situated in the heart of the Port of Pittsburgh, the leading inland port in terms of tonnage, which handled almost 53 million tons in Calendar Year 1999. Figure II-2 shows the Emsworth pool.

2. CONSTRUCTION HISTORY.

The locks and original fixed crest main and back channel dams were constructed during 1919 - 1922. Emsworth Locks and Dams replaced three nineteenth century vintage projects, Davis Island on the Ohio River and Locks and Dams 1 on both the Monongahela and Allegheny Rivers. The original dams were concrete fixed crest weirs on each side of Neville Island. Except for a small portion adjacent to the locks, both dams were founded on wood piling. Significantly, the project design was considered experimental at the time as it consisted of the first fixed crest dam and first double locks on the Ohio River System. So much concern was expressed over this project that plans for additional fixed dams were held up until users and the general public became convinced that the fixed dam was no threat to businesses and property and that it functioned as intended. As evidenced by the subsequent construction of fixed dams on the Ohio River and elsewhere, this experiment was considered a success.

The dams were reconstructed in 1935-1938 to provide gated crests and to raise the Emsworth pool by seven feet to its present 710' NGVD. The new, gated dams were constructed immediately upstream of the original fixed crest dams, and then the original dams were cut down seven feet to function as stilling basins and aprons. It was not necessary for the lock chambers to be altered since they were sufficient to withstand the loads of increased head. See PLATE H-1 in the General Engineering and Reliability

Appendix (Appendix A), Section A.4, for original dam configuration and its alteration. The gated dams were founded on steel piles driven to refusal.

3. GENERAL CLIMATOLOGIC AND HYDRAULIC CHARACTERISTICS

a. Climate

The climate at Pittsburgh, PA (Emsworth area) is temperate with a seasonal variation ranging from a normal monthly temperature of 72° in July to 26° in January. The average annual temperature is 50°. The temperature extremes are plus 103°F and minus 20°F.

b. Precipitation

Precipitation over the region is distributed fairly uniformly throughout the year. The normal annual precipitation is 36.8 inches in Pittsburgh, PA. Snowfall accumulates to a depth of 6 inches nearly every winter, although this snow cover usually is not continuous. Normal annual snowfall is 30 inches. The recent blizzard of March 1993 produced 26 inches of snow accumulation in 24 hours.

c. Gages

The U.S. Army Corps of Engineers, U.S. Geological Survey, and National Weather Service maintain various stream and weather gages at Pittsburgh, Emsworth, and Dashields. They provide continuous and overlapping weather and stream data for this area for a lengthy period of record (some river stage records go back to the 1700's).

d. Flow Characteristics

Analytical flow frequencies at Pittsburgh are as follows: 1 year=173,000 cfs; 10 year=282,000 cfs; 100 year=394,000 cfs; 500 year=480,000 cfs. The average annual flow is approximately 35,000 cfs.

e. Extreme Events

The minimum flow of record occurred August 1930 with 1,100 cfs. The 7-day 10-year mean low flow is 4,800 cfs with the present reservoir system. The maximum flood of record was March 1936 at 740.2 feet NGVD and 574,000 cfs, and 4 inches of rain recorded at Pittsburgh. The corresponding elevation and flow with the present reservoir system would be 729.5 and 355,000 cfs. January 1996, a recent flood reached 728.8 feet NGVD and 369,000 cfs, but would have reached 738.5 without our present flood control reservoir system.

f. Pool Characteristics

Normal upper pool at Emsworth is 710.0 feet NGVD. The lock and dam operators typically hold it at 710.6. The normal lower pool, or tailwater is 692.0. The ordinary high water level is 711 feet NGVD at the dam and 714.6 feet NGVD at Pittsburgh. Riverboat navigation is suspended when the Pittsburgh 'point' gage equals 716.2 ft. and the 'point' flood stage is 719.2 ft. NGVD.

g. Watershed characteristics

The drainage area above the dam is 19,428 square miles. The watershed is characterized by steep and narrow valley terrain in the headwaters of the Allegheny and Monongahela Rivers to gently rolling hills and plateaus in the main stems of the rivers. The Monongahela and upper Ohio Rivers have mostly high stream banks with small floodplains. The total relief ranges from 4,700 ft. NGVD in the upper Monongahela River basin to 710 at the dam. In Emsworth pool, the approximate pool storage volume is 42,000 acre-feet, and the average width of the river is 1500 feet.

h. Ice & Debris

Emsworth gates have no overflow capability, and since it is the first dam on the upper Ohio, it is a natural stopping place for ice and debris. Much of the Monongahela River ice from below Locks and Dam 4, and significant amounts of Allegheny River ice ends up in the Emsworth Pool. This project also has a serious debris accumulation problem.

Ice passage beneath tainter gates requires that they be raised a minimum of about 4 to 5 feet to draw ice pieces beneath. A gate opening of about 5 ft. requires a tailwater depth of 16.6 ft. on the lower gage at Emsworth. This operating guideline was developed to help reduce the potential for damage to the downstream sill and bed protection. Operators estimated that a discharge in the 36,000 to 42,000 cfs range (25 to 30 ft total gate opening) is needed to continuously draw loose brash ice towards the dam. However, due to average winter discharges of 44,000 cfs, there is little opportunity to pass ice at below average winter discharges. Unfortunately, extreme cold and heavy ice often coincide with periods of low flow.

i. Hydraulic Characteristics

Emsworth Locks and Dams are located on the Ohio River 6.2 river miles from the Point of Pittsburgh and the joining of the Monongahela and Allegheny Rivers. Emsworth consists of two dams that are separated by Neville Island. The lower pool is controlled about 7 miles downstream by Dashields fixed-crest dam (elevation 692.0).

j. Gate Operations

The dams are comprised of 14 gated spillway bays each 100 feet side. All gates are operated by schedule to maintain a normal pool elevation of about 710.6 at Pittsburgh for discharges up to about 75,000 cfs after which increasing flows cause the stage to increase. By the time river flows reach 150,000 cfs, all the gates have been raised out of water and open river conditions are established.

4. EMSWORTH REAL ESTATE - GOVERNMENT OWNED LAND

A total of 18.71 acres is being used as support land for the project. It is broken down as follows: Fee Land, Easements, and Licenses. See Exhibit A in the Real Estate Plan (Appendix G) for locations of all tracts noted below.

a. Fee Land

There is a total of 15.25 acres of fee land owned by the US Government for this project, to include 3.83 acres on the right bank and 10.14 acres on the left bank of the main channel, and 1.28 acres on the back channel.

b. Easements

A total of 2.79 acres are easements used in support of the project. These easements are further broken down into 1.34 acres of Permanent Road Easements and 1.45 acres of flowage easements.

c. Licenses

There are 4 existing licenses totaling 0.67 acres and consist of a tract for a sewer line (0.04 acres), a private grade crossing, pedestrian tunnel and parking area (0.51 acres), a grade crossing (0.08 acres), and a grade crossing (0.04 acres).

5. MAJOR DAM FEATURES.

This section describes all major components of the gated dams. The main and back channel dams are basically the same, except that the main channel has eight gates and the back channel has six gates, and that the main channel has a 34 foot weir adjacent to the river wall whereas the back channel has none. Each component and their primary functions are described below.

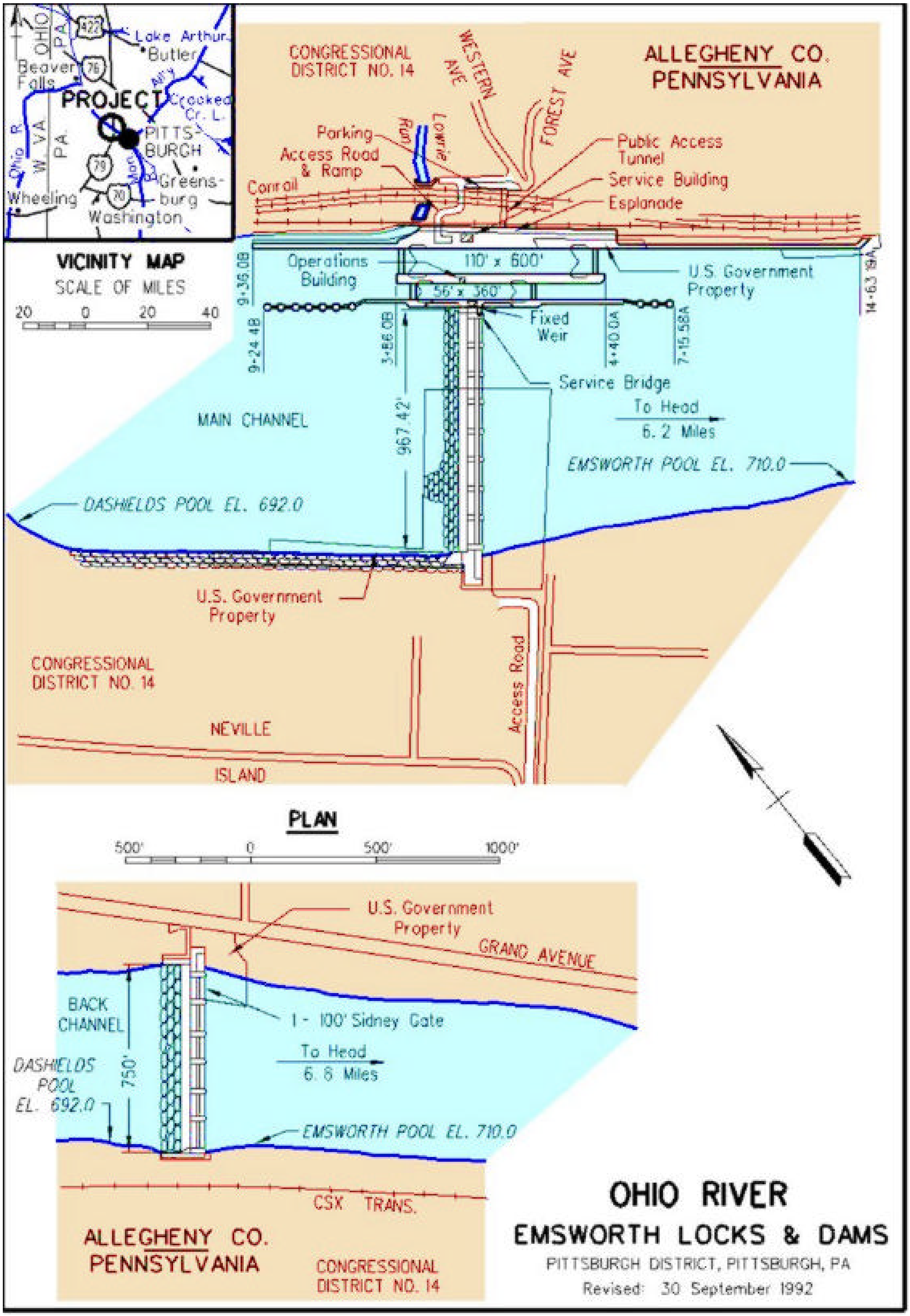

Figure II-1 - Emsworth Locks and Dams

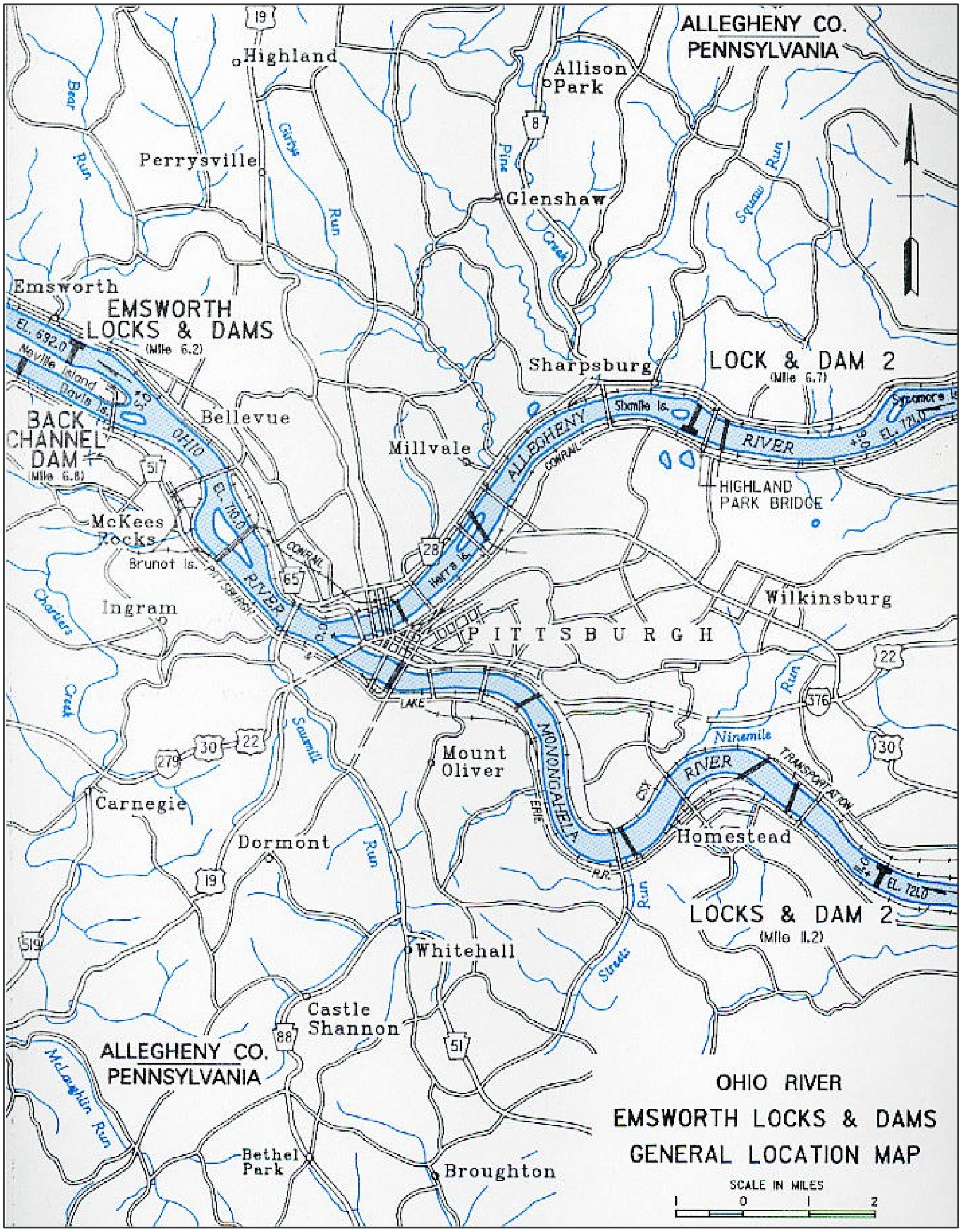

Figure II-2. Emsworth Pool

Photo II-1 - Emsworth Main Channel Service Bridge

a. Service Bridges

The main channel service bridge is shown as Photo II-1. The service bridge for each dam consists of two built-up plate girders spaced at eight feet center-to-center. The bridge is categorized as "fracture-critical" by the Federal Highway Administration (FHWA) standards, due to non-redundancy in the superstructure design. Each service bridge utilizes a reinforced concrete deck to span between the two main girders. Crane rails are attached to the top flange plates of the main girders, which act as a track to carry the locomotive crane. A monorail beam for the bulkhead crane is connected to the underside of the downstream bridge girder flange plates.

The major function of the service bridges is to support the emergency bulkhead crane and locomotive cranes. The service bridge also provides access to each pier for maintenance and operation of the dam gates, gate hoisting machinery and electrical systems.

Photo II-2. Emsworth Main Channel Locomotive Crane

b. Locomotive Cranes

The main channel locomotive crane is shown in Photo II-2. Each service bridge is equipped with one locomotive crane. The crane rails are positioned along the top flanges of the upstream and downstream girder. Steel plate spacers are used to elevate the rails above the rivet heads (staggered along the top flange plate), and steel clips are used to secure the rails. . The locomotive cranes are used for servicing and repairing the lift gates.

c. Bulkhead Cranes

Each dam is equipped with one bulkhead crane. The bulkhead crane are suspended on a 18-inch deep "I" beam, attached to the bottom flange plate of the downstream girder of each dam. The function of the bulkhead cranes is to transfer the emergency bulkheads from the storage pits near the dam abutments into the gate bay. The bulkhead crane lifts one bulkhead unit at a time from the bulkhead storage pit and travels to the gate bay for placement. The process continues until each of the four bulkhead units is moved into place and stacked on top of each other. The lifting capacity of each bulkhead crane is 20 tons.

Photo II-3. Emsworth Vertical Lift Gate Truss Assembly

d. Vertical Lift Gates

The main channel dam consists of eight vertical-lift gates, one of which is shown in Photo II-3. The back channel dam consists of five vertical and one tainter-style gate referred to as a Sidney gate. All gates are 100' wide and all but one are vertical lift gates. The only tainter gate (also known as a Sidney Gate) is on the back channel dam in gate bay 9. The vertical-lift gates have top and bottom trusses consisting of built-up members placed in a horizontal direction. The upstream center-to-center spacing of trusses and effective damming height above the sill is 11', which tapers to a downstream dimension of 6' 3".

The vertical-lift gates were repaired and modified prior to and during the 1981-83 Major Rehabilitation project. Prior to this Major Rehabilitation, the overflow feature of the vertical-lift gates was removed. Overflow sections attached to the top truss were removed and replaced with a skin plate extension, which was added to the upstream face of the top truss. Also, the gate sills were modified to provide a seal surface. During the Major Rehabilitation, the gates were further repaired according to field inspection and determination of structural integrity of members and rivets.

Movement of each gate is made possible by four truck assemblies, one upper and one lower on each side of the gate, that ride on tracks embedded within the concrete dam piers. These assemblies transfer loads on the gate into the piers and guide the gate while being raised or lowered to the required opening for discharging flows.

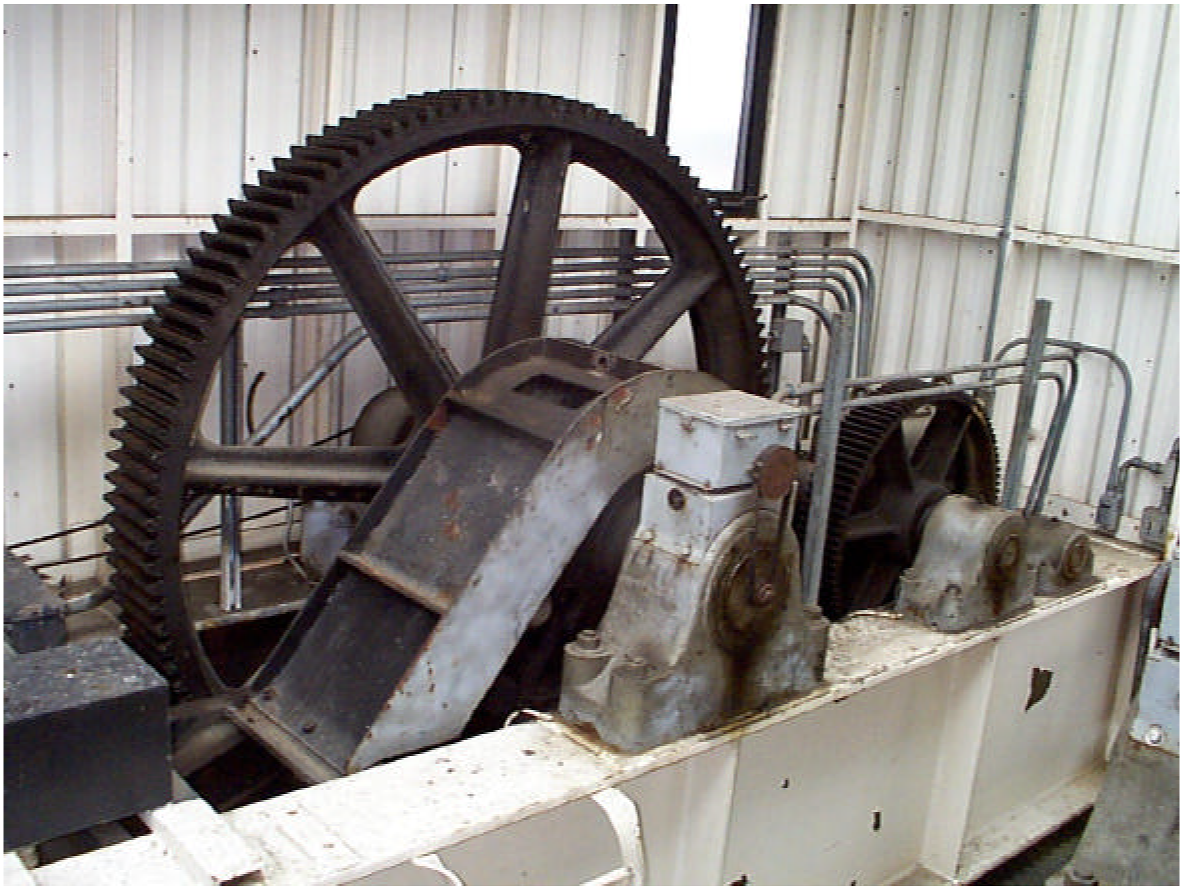

Photo II-4. Emsworth Vertical Lift Gate Machinery

e. Vertical Lift Gate Machinery

The vertical lift gate machinery for each gate is comprised of two independent systems. Each system is comprised of one roller chain attached to the end of each gate and a hoist located in a metal housing directly overhead. The hoist machinery located in one housing is shown in II-4. Each hoist consists of 2 sets of spur gears, a helical gear set, a secondary reducer, and a worm gear primary reducer driven by synchronous-type wound rotor electric motor. The motors must maintain the gates at a nearly level position throughout their range of travel. A travel limit switch is provided at one end of each gate to prevent over-travel.

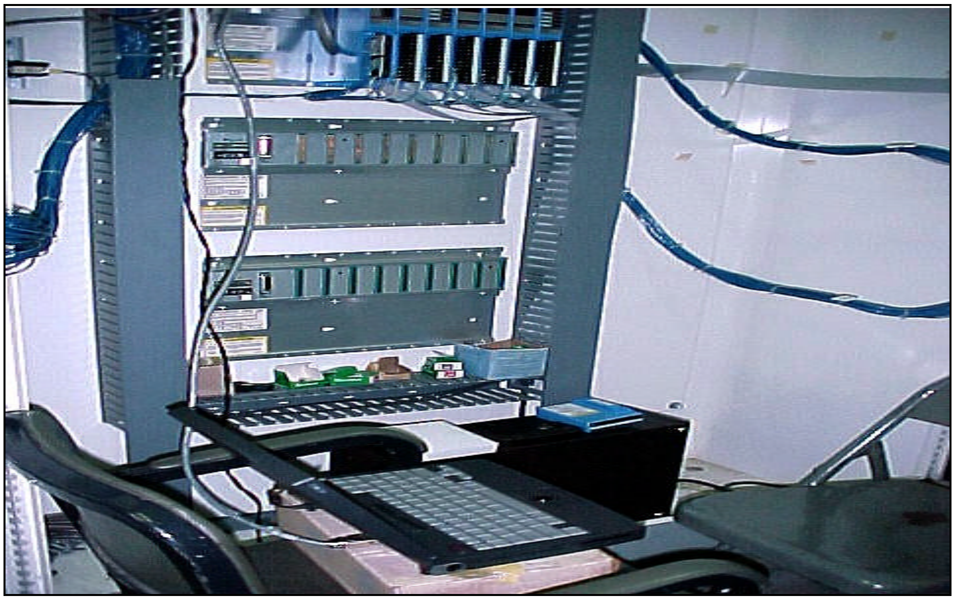

Photo II-5. Programmable Control Panel

f. Electrical Systems and Appurtenant Features

1) Power Source

The normal source of power to the main channel dam is supplied through two 480-volt redundant feeders from the lock river wall power panel. The normal source of power to the back channel dam is provided through a separate service from the facilities of the Duquesne Light Company. The Programmable Control Panel is shown in Photo II-5. The electrical service is supplied at 480 volts, 3 phase, 3 wire, 60 Hertz. Emergency power is provided to the main channel dam by the lock diesel engine driven generator through an automatic transfer switch. A separate diesel driven generator and automatic transfer switch provides emergency power to the back channel dam and is located in the back channel control building.

2) Power Distribution System

Two redundant power feeders supply power to each dam. The power feeders enter each operating pier and terminate into a manual transfer selector switch. A feeder then supplies power to the motor control panels that contain the motor starters for the gates. The motor control panels also contain the motor resistors, accelerating contactors, programmable controllers, and other power and control appurtenances. There are two motor control panels, motors, limit switches and gate position sensors for each gate. A separate power feeder is provided for main channel dam lighting. Voltage for the lighting feeder is supplied at 480 volts, 3 phase and is transformed to 120/208 volts, by a 3 phase lighting transformer at pier 5. Lighting panels are located at each pier. The lighting feeder for the back channel dam is provided 120/208 volts, 3 phase and provides power to the lighting panels located at each pier.

All main and back channel dam gates were designed to be remotely operated from the main channel control panel located in the middle wall operations building for the main channel dam, and the back channel control panel located in the control building for the back channel dam. Because of various problems with the gate hoist system, remote operations have been suspended. These problems are discussed later in this report. The dam gates can also be operated locally at the motor control panels (MCP) or the deck control stations. The control system utilizes first generation programmable logic controllers (PLC's). Communications is via RS-485 protocol at 9600 baud. The gate position sensors provide signals to the PLC's. These signals are used by the control system for synchronization and for displaying the gate height.

3) Lighting System

The lighting system for the main and back channel dam consist of high-pressure sodium (HPS) luminaires. A walkway lighting system is provided for the service bridge. Gate floodlighting, and upstream and downstream floodlighting is provided from the service bridge on both the main and back channels. The wiring of the fixtures consists of standard electrical wiring conventionally placed through conduits and strategically located pull boxes.

g. Dam Piers and Abutment

Main channel Pier #1 is founded on medium hard, gray sandstone. Main channel Gate Bay #1 is founded on steel bearing piles that were drilled into rock and back-filled to elevation 685.5 with sand and gravel. All other monoliths on both dams are founded on steel piles driven to refusal (30-40 blows per inch) in silty sandy gravel. An upstream and downstream steel sheet-pile cutoff between the stilling basin and gated dam foundations was not driven to rock.

Photo II-6. Main Channel Emergency Bulkhead

h. Emergency Bulkheads

Each dam is equipped with one emergency bulkhead assembly to accommodate closure of one gate bay and are designed to be installed under flowing conditions. The main channel emergency bulkhead is shown in Photo II-6. Each assembly consists of four sections that are stored in pits near one abutment. Each unit consists of a top and bottom truss, with a damming height of 4’ 2 ½”, and is framed to withstand horizontal forces and vertical dead loads. The trusses are built-up sections with a back-to-back angle depth of 11’ 7 ¾”. The overall length of the bulkhead sections is 102’ 3 ½” centerline of roller to centerline of roller. The bulkhead sections are made of structural-grade aluminum alloys and are of riveted construction. Placement of the bulkhead units in a Gate Bay is performed by means of an electric motor-driven hoist, which travels suspended on a monorail track attached to the bottom flange of the service bridge downstream girder and through slots in the dam piers. The hoist retrieves one unit at a time from the storage bay, travels to the placement bay and lowers the unit into place.

i. Stilling Basin/Apron and Scour Protection

As part of the alterations to the dams in 1938, the stilling basin/apron structures for each dam were constructed using a portion of the original fixed crest dam as shown in Plate H-2 in

Appendix A, Section A.4. The floor and apron was selected and designed after a series of physical model tests by Carnegie Institute of Technology had given the most satisfactory ratings in velocity measurements and scour observations. During the Major Rehabilitation in the 1980's, the stream bed immediately downstream of the dams' aprons was graded, shaped and scour-protected with a heavy blanket of 5' derrick stone over a 3' graded stone blanket and a 1' filter blanket. Scoured areas upstream of the main channel dam were similarly filled, and stone protection was added. The graded stone is shown in Photo II-7.

Photo II-7. Stone Blanket Material

6. REPAIR HISTORY FOR DAM COMPONENTS (1937-PRESENT)

Sub-sections 6 and 7 provide a detailed review of past repair work to the current dam structures. (For an abbreviated review, the reader might prefer to skip ahead to Section III).

To help provide some context for the discussions and analyses that follow, Table II-1 lists the major remedial measures for the dams commencing with the construction of the gated structure in the mid-1930's. Major rehabilitation work on the dam included refurbishing of the vertical lift dam gates and the placement of scour protection downstream of both dams. Detail of work since the 1970's is provided by text below. Major work items during this rehabilitation are shown in Table II-2 and addressed in some detail in the following two sections.

Table II-1 Maintenance History Of Gated Dams

Year	**Description of Work**	**Cost ($)**
1935-1938	Construction of gated dams, old dams cut down and used as aprons.	2,800,000
1938	Placed fill under back channel dam apron.	6,000
1940	Cleaned and Painted Main Channel Service Bridge & Emergency Bulkheads	6,923
1941	Cleaned and Painted Back Channel Service Bridge & Emergency Bulkheads	8,257
1954	Repaired Sidney Gate and Painted Service Bridge	11,460
1958	Painted exterior lift gates and installed diesel driven generators on back channel dam	55,000
1961	Painted 13 Vertical Lift Gates	73,595
1961	Encased timber seals in stainless steel	1,058
1964	Repaired monorail track and trolley collectors	6,221
1966	Repaired lift gate seals	13,406
1968	Repaired lift gate seals	19,552
1973	Repaired dam gate #14 from drop in Nov. 1972	257,500
1975	Repaired tainter gate.	22,100
1977	Completed rehabilitation of dam gates and modifications to gate sills (started 1973)	1,002,800
1977	Treated void under apron at main dam Gate Bay #3.	159,800
1978	Drilled apron to investigate for voids, Gate Bay #5	15,000
1978	Renovated dam lift gates #7, 8 & 11	34,800
1982-85	Major Rehabilitation of Dam (See Table II-2)	9,000,000
1985	Repaired scour protection downstream of Gate Bays 3, 4 & 5	N. A.
1986	Replaced dam crane power collector system	140,301
1986	Complete major rehabilitation work on dam (See Table II-2)	
1987	Replace dam lift gate seals on gates 5, 6, 8, 4, & 8	51,379
1988	Replace two 20-ton bulkhead cranes.	432,760
1988	Repaired damage to lift gate 14 from breaking hoist chain in Feb. 1988	86,362
1990	Modify vertical seals on dam lift gate No. 14	52,766
1990	Revise lift gate side seals and install level sensor, dam gate No. 13	37,987
1991	Revised lift gate side seals and installed level sensors on dam gates 11 and 12. Sensors remain to be hooked up	66,898
1992	Modified side seals on back channel dam lift gate 11	2,092
1996	Repaired structural damage and partially replaced skin plate on dam gate 2 due to barge accident	176,886 est.
1998	Truck Assembly on gate nos. 1, 2 reinstalled	152,000
1999	Truck Assembly on gates nos. 6, 7, 8 reinstalled	138,000
2000	Truck Assembly on gates 1, 4, 12, 13 reinstalled	169,000

N.A. designates cost not available. All costs represent actual or estimated expenditures in year(s) of work

Table II-2 Major Rehabilitation Activities
EMSWORTH DAMS
1982-1986

Provide scour protection at end of dam apron
Grout voids beneath apron and abutment
Recondition vertical lift gates
Clean and paint service bridges and bulkhead storage pits
Rehabilitate bulkheads
Install new electrical systems

What is very apparent in the work history is the onset of additional maintenance and repair activities commencing in the early 1970's. This work history may well presage a continuation or even an acceleration of unplanned expenditures to keep the dam operational in the 21st century.

During the period between December 1972 and April 1973, a detailed inspection by the District's structural engineers was conducted in which (random) patterns of deterioration were detected in all gates -- specifically heavy pitting in the lower sections of gate and loss of section through corrosion to the downstream chord of the two lower trusses. For those reasons, the District decided in 1973 to convert all Emsworth dam gates for underflow operation only. Such operation would eliminate the periodic loading of gates by vertical water loads during overflow operation and, by removal of the overflow plates, lessen the tendency for corrosion of truss members. Between 1973 and 1977, the thirteen vertical lift gates were renovated and converted to non-overflow gates by removing the overflow plate and replacing it with a 1'-2" extension of the skin plate. Renovation work consisted of replacing deteriorated diagonal truss members along the top of the gate, replacing deteriorated rivets and modification of gate sills to provide a bottom seal surface. On five gates, the bottom seal, bearing pad and gate sill were modified, as well as sandblasting and painting. The concrete gate sills were extended to provide a continuous support with a rubber seal for underflow operation. However, it was noted in subsequent inspections that new truss members showed early signs of rusting (replaced members given a prime coat only, not painted).

7. 1980'S MAJOR REHABILITATION OF DAM COMPONENTS

The main features of the work performed on the dam during the initial major rehabilitation project consisted of completing the reconditioning of all gates, renovating the dam bulkheads and replacing bulkhead crane conductor rails, and cleaning and painting the service bridge. A remote control system for the dam gates was installed along with new power service for the main channel dam. Erosion protection was placed downstream of the dam, in both the main and back channels, and voids beneath the dam apron were grouted. Additional detail is provided below.

a. Dam Gates

Structural repairs were made to members comprising the lift gates that were heavily corroded or deteriorated. This included portions of the skin plates and miscellaneous members on the upper and lower trusses. For the top trusses, missing, loose or deteriorated rivets on the downstream chord were replaced with high strength bolts. For the bottom trusses, two diagonal members were replaced and five vertical members were reinforced with plate. Downstream girders were modified through reinforcement of vertical stiffeners by removal of the outstanding leg angle and replacing it with a plate. End frames were modified through replacement of vertical stiffeners where necessary and replacement of rivets with high strength bolts

For the eight gates not repaired previously, the existing gate timber seals were replaced with rubber seals. These gates were also cleaned and painted. The Sydney gate (gate no. 9 on the back channel dam) was cleaned and painted, deteriorated portions of the skin plate, structural members and seals were replaced, and deteriorated rivets were replaced with high strength steel bolts.

b. Scour Protection

Some localized scoured areas under the downstream end of the dam aprons were grouted with tremie concrete where voids were found. Similar scoured areas were found along the upstream face of the main channel dam. These holes were grouted and protected with graded stone.

Following the grouting of the holes, two layers of "rock blanket" scour protection, consisting of a top, protective layer of 5 ft. cut derrick stone resting on a 3 ft. graded stone blanket were placed downstream of the apron to help protect the apron. Both of these layers rest on a 1 ft. filter blanket layer of bedding material. The top of the stone was placed level with the apron and sloped downward at 1V on 3H into the existing topography to allow for flow expansion.

c. Dam Concrete

No significant repairs were made to the concrete of the dams.

d. Structural Steel Members

Dam gate and service bridge main girders were sandblasted and repainted only in localized, intermittent areas where the coating was peeling off. None of the primary steel members consisting of the service bridge main girders, locomotive crane rails, bulkhead crane monorail, dam gate skin plates or truss members, bulkheads were totally cleaned to base metal and recoated with primer and finish coat applications.

The main and back channel dam electrical system was replaced in 1984. Most of the electrical distribution equipment was included in the rehab with the exception of the dam gate motors and limit switches. The dam gate motors are 15HP wound rotor type, and have shown signs of deterioration. Recent meter readings have shown significant changes in the winding insulation and soon a decision will have to be made as to whether to replace or rewind the motors. Because of the presence of moisture in some of the pier rooms the overall equipment condition varies.

SECTION III.   EMSWORTH POOL

This section describes the areas that could be impacted either economically or environmentally during the planning period by any of the alternatives considered. As discussed in Section III, economic impacts are primarily associated with potential consequences arising from failure of dam components that in turn cause loss of Emsworth pool. Environmental impacts may arise due to loss of pool (reaches where the river elevation is controlled by Emsworth Dams), construction activities, environmental design and mitigation features. The environmental setting described herein includes significant resources covered by applicable laws, such as endangered species, cultural and historical laws. Economic costs (or risk costs) are summarized in Section V and described in detail in the Economics Appendix (Appendix B). Environmental impact details are summarized in Section V and described in detail in the Environmental Assessment.

1. DESCRIPTION

The Emsworth pool extends 6.2 miles up the Ohio to the Point at Downtown Pittsburgh, and then 6.7 miles up the Allegheny and 11.2 miles up the Monongahela. Most of the pool is within the city limits of Pittsburgh. The shore-side area is heavily developed, and the pool is used extensively by a multitude of users.

2. USES OF THE POOL

The principle uses of the navigation pool are (1) navigation, (2) recreational boating, (3) commercial and recreation docking, and (4) withdrawal of water for public and private water consumption.

a. Commercial Navigation

Over 239 million tons of commodities are transported by barge annually on the Ohio River. Traffic through Emsworth has been primarily in the 20-25 million ton range for the last 25 years or so. Historic and projected traffic is shown in Table III-1. Principle commodities serviced by Emsworth are usually coal and crude materials (primarily sand and gravel, but which also includes forest products, wood and chips, pulp and waste paper, soil, and stone). In 2000, over 72% of the traffic was coal and another 15% was crude materials. Approximately 5,000 tows with more than 23 million tons transited through Emsworth Locks in 1998. While this is below the 32 million ton capacity of the main chamber, both chambers are used to efficiently service this traffic. The auxiliary chamber typically serves smaller tows, recreation craft and other vessels that fit in the smaller 56'x360' auxiliary chamber. Approximately 25% of commercial tows and 90% of recreational craft used the smaller auxiliary chamber in 1999.

The transportation savings attributable to commercial traffic through Emsworth is estimated at about $300 million annually. This traffic depends upon the provision of a reliable 9' navigation pool at Emsworth, which is dependent on operation of the gated dam. Traffic is expected to increase slightly through 2070, at about 0.6% per year. Therefore, the project benefits should remain strong throughout the analysis period.

Table III-1 Historic and Projected Traffic
Emsworth L&D
(millions of tons)

Historic Year	Historic Tons	Projected* Year	Projected* Tons
1930	10.0	2000	26.0
1935	8.4	2005	28.1
1940	12.5	2010	28.5
1945	15.9	2015	29.3
1950	16.4	2020	30.1
1955	22.6	2025	31.1
1960	18.7	2030	32.1
1965	22.9	2035	33.2
1970	24.1	2040	34.2
1975	24.7	2045	35.4
1980	21.2	2050	35.6
1985	17.2	2055	36.0
1990	23.1	2060	36.4
1995	23.1	2065	36.7
2000	22.3	2070	37.0

* projected traffic assumes current navigation system constraints -- no major expansion of lock capacity in the Ohio River system beyond that already authorized in 2001.

The project allows provides benefits to recreational boaters that are estimated at about $1 million per year. Recreational activities typically associated with major inland river reaches such as Emsworth include boating, swimming, fishing, sight-seeing, and water skiing. Table III-2 shows current and projected recreational days and benefits as provided by the Emsworth pool

Table III-2 Projected Recreation Days
And Recreation Benefits

Year	Recreation Days	Recreation Benefits
2005	164,272	985,633
2010	174,229	1,045,375
2015	184,789	1,108,737
2020	195,990	1,175,940
2025	207,869	1,247,216

In terms of number of recreational vessels served, Emsworth has ranked in the top 3 of all nineteen Ohio River Locks and Dams throughout the 1990s. The 1990 figures, which ranged between 2700 to over 6000 craft per year, are shown in Table III-3.

Table III-3 Historic Emsworth L/D Recreation Traffic

Year	# of Vessels
1990	4,099
1991	6,140
1992	3,976
1993	4,588
1994	3,804
1995	4,250
1996	2,691
1997	3,308
1998	3,125
1999	3,938
2000	2,765

b. Docks, Mooring and Fleeting Areas

The private docks, mooring and fleeting areas located in the Emsworth pool are shown in Table III-4.

c. Recreational Facilities

Recreation facilities that would be directly impacted by loss of Emsworth pool are shown in Table III-5.

d. Water Intakes

All private and public intakes that would be directly impacted by loss of Emsworth pool are shown in Table III-6.

e. Bridges and Railroad Facilities

Allegheny County is renowned for the number of bridges within its boundaries, and this is confirmed by facilities just within Emsworth pool. There are 27 bridges spanning this pool, 3 in the Ohio River, 13 in the Allegheny River, and 11 in the Monongahela River. Active railroad tracks line both shores. The CSX line is only a hundred feet behind the Emsworth esplanade on the lock side. Norfolk Southern operates the line on the opposite bank.

Table III-4 Commercial Docks, Mooring, & Fleeting Areas

	Miles Above Point In Pittsburgh		
	Left Bank	Right Bank	Commodity/Use
Allegheny River		1.0	Mooring
	2.7		Petroleum
		3.3	Mooring
	3.4	`	Sand & Gravel
	4.4		Petroleum
		5.0	Various Commodities/Mooring
		5.4	Sand & Gravel
		7.0	Scrap Barges/Mooring
	7.5		Mooring/Repair
		8.3	Construction Equip/Mooring
	Miles Above Point In Pittsburgh		
	Left Bank	Right Bank	Commodity/Use
Monongahela River	1.1		Sand & Gravel
	1.2		Sand & Gravel
		2.1	Sand, Gravel, Coal
	4.7		Mooring
	5.7		Petroleum
	Miles Below Point In Pittsburgh		
	Left Bank	Right Bank	Commodity/Use
Ohio River		0.6	Fleeting
		0.7	Fleeting
		1.0	Fleeting (Idle)
	1.1		Fleeting
		1.8 (BC)	Fuel Oil
	2.9 (BC)		Sand & Gravel
	3		Sand & Gravel
	3.00 (BC)		Petroleum Products
		3.0	Maintenance, Repair, Fleeting
	3.0 - 3.2		Petroleum Products/Chemicals
		4.0	Steel Products
	5.0-5.3		Pig Iron (Idle)
		5.10 (BC)	Crushed Stone & Gravel
	5.3-5.5		Coal
	5.6		Chemicals
	5.7-5.9		Petroleum Products

Table III-5 Existing Recreation Facilities Within Emsworth Pool

River	Facility	Number
Allegheny	Fishing Access - Public	11
	Park	2
	Boat Ramp	0
	Marina	8
	Other	1 (Rowing Club)
Monongahela	Fishing Access - Public	7
	Park	2
	Boat Ramp	1
	Marina	0
	Other	1 (River Cruise)
Ohio	Fishing Access - Public	4
	Park	0
	Boat Ramp	0
	Marina	5
	Other	0

Source: Recreational Use Survey and Valuation of Recreational Use Types for Portions of the Allegheny, Monongahela and Ohio Rivers, Terrestrial Environmental Specialists, Inc.. *et al*, 1996

Table III-6- Water Intakes and Wells Operating in Emsworth Pool

			Intakes		Wells	
	Owner	R.M./Bank	Invert	Pipe Size(s)	Well Bottom	Pipe Size(s)
Allegheny River	Equitable Life Assurance Soc. (Gateway Building Complex)	0.4 Left	700.0	72"x60"		
	Shaler Township	4.6 Right			Unknown	8-16"
	Etna	5.3 Right			704.46	6"
					674.87	6"
					670.36	6"
					675.42	6"
	Sharpsburg Borough	6.1 Right			700.00	16"
					700.00	18"
	Sharpsburg Borough	6.4 Right			700.00	5-12"
Mon River	Western PA Water Co.	4.5 Left	698.0	36"		
			698.0	48"		
Ohio River	Orion Power	2.3 Right Brunot isl	701.2	2-12"		
	West View Borough	4.6 Left Davis Isl			667.00	12-8"
					680.00	9-6"
		5.0 Right Nev Isl	705.0	48"		
	Shenango Steel	5.3 Right Nev. Isl.	706.0	60"		

3. ENVIRONMENTAL SETTING

The Emsworth pool includes most of the riverfront in the Pittsburgh area, an area that was historically characterized by its massive steel making complexes. As a result fish species suffered as a result of gross water quality degradation. Species that could survive in smaller rivers and streams persisted in more remote, non-urbanized and unpolluted refuge headwaters. During the 1950’s and 1960’s, the Emsworth pool showed a low diversity and poor quality fishery dominated almost exclusively by pollution tolerant carp, brown bullhead, emerald shiner and gizzard shad.

The fishery of the upper Ohio River is in the process of recovery from generations of degraded and limiting water. Beginning in the 1970’s and continuing to the present, with improving water quality, fish began to invade and re-colonize the Emsworth pool. The first species to appear were those that had persisted in upstream water quality refuges. Re-colonization of sauger, spotted bass, drum, mooneye, goldeneye, silver chub and the buffalo fishes occurred later and apparently originated from sometimes remotely distant downstream areas from where they had to make multiple lockages up through the locks and dam structures of the Ohio River navigation system. Paddlefish did not return naturally but were reintroduced by the Pennsylvania Fish and Boat Commission in a program that started in 1991.

It has been estimated that at one time the waters of the upper Ohio River drainage probably supported 120 species of fish. When water quality along the river was degraded, no less than 35 species were extirpated from the Ohio River drainage portion of Pennsylvania. To date, only nine of these 35 species have not returned to these recovering streams.

Wooded riparian habitat along the Emsworth pool could potentially be excellent Indiana bat habitat where the river might be used as a forage area. However, most of the floodplain adjacent to the pool has been severely impacted by filling, grading and deforestation. Riverbank vegetation is classified as immature riparian woodland with the canopy dominated by native wetland woody plant species and the under story by exotic plant species.

SECTION IV. PROBLEM IDENTIFICATION AND STUDY OBJECTIVES

The starting point for technical analysis of Emsworth Dams is a description of problems already being encountered with the existing facilities. This Major Rehabilitation Report is primarily in response to on-going problems during dam gate operation and identified during various inspections of the main and back channel dam gates and scour protection. These problems are described in the following paragraphs.

1. PROBLEMS AND OPPORTUNITIES

The four most significant problems are:

(a) Severe corrosion of gate truss members that make the gates vulnerable to sudden failure, especially by unanticipated impact loads.
(b) Old truck assemblies that failed at an alarming rate during the latter half of the 1990s and although repaired are not considered reliable.
(c) Antiquated electrical and mechanical systems that can not be relied on to safely operating the gates
(d) Scour protection that has been displaced in several locations, thereby exposing some stilling basin/dam apron foundation material to the potential of erosion.

Secondary problems relate to fair to poor condition of:
(e) Some concrete on the dams and service bridges; and
(f) Several service bridge components, including concrete slabs and the rail systems for the locomotive cranes which perform critical maintenance operations.

Further complicating maintenance of this equipment is the fact that various mechanical and electrical components are obsolete and that replacement parts must be fabricated, thereby increasing the likelihood of problems with serious consequences, including the loss of Emsworth pool. Further details for all major dam components are provided below.

These problems constitute the starting point or initial risk inherent in all alternatives. Work measures developed in response to these risks would be designed to either more quickly react to unexpected component failures or lessen the risk of such failures.

a. Gate Truss Members

The truss members of all dam gates are in an advanced stage of corrosion and operational difficulties continue to occur despite the renovation work in the 1970's and subsequent work performed during the major rehabilitation. Truss members in the lower portions of these gates are within the splash zone and are subject to severe corrosion. Recent inspection and measurement of lower steel truss members show numerous components are corroded such that less than 50% of the original member remains. An example of this corrosion is provided in Photo IV-1. This situation is complicated by the fact that the design of the gates provides no allowance for runaway barge or ice impact loading. If such loading were to occur, these gates would be likely to fail.

Photo IV-1. Corroded Dam Truss Members. (Note rivets replaced with nuts/bolts during rehabilitation in the 1980s)

Maintenance of these members is extremely difficult due to factors such as accessibility, the sheer number of truss members per structure and harsh corrosive environment. Between 1973 and 1980, deteriorated diagonal truss members were replaced at the same time as the gates were being converted to non-overflow mode only. Ironically, these new members were found to be corroded during inspections only a few years later (prior to the major rehabilitation).

b. Gate Truck Assemblies

Beginning in 1998, operation of the dam gates has been plagued by failures of the bottom truck assemblies. Each vertical lift gate has a wheeled truck assembly on each corner (bottom and top) that moves in embedded vertical metal tracks during raising and lowering operations. These truck assemblies are subjected to highly corrosive conditions from spray through gate side seals and from the discharges under the gate. The extent of the corrosion has become so severe that parts of the assemblies have failed allowing the gate structures to move downstream against the pier, rendering the gates inoperable. Out of a total of 52 truck assemblies on 13 gates, a total of 16 assemblies on 8 gates have undergone emergency repairs in the last 3 years. These recurring problems have resulted in emergency repairs and renovation of the assemblies by District maintenance personnel. (See Table IV-1)

Table IV-1 Truck Assembly Renovations

DATE	GATE	ASSEMBLY	REPAIR DURATION (DAYS)	COST
June 1998	#2	Both Lower	64	$97,900
August 1998	#1	Lock Side Lower	41	$48,950
October 1998	#6	Both Lower	108	$42,900
February 1999	#7	Both Lower	35	$42,900
April 1999	#8	Both Lower	105	$42,900
September 1999	#4	Both Lower	112	$42,900
January 2000	#13	Both Lower	67	$42,900
March 2000	#12	Both Lower	42	$42,900
March 2000	#1	Abutment Side Lower	36	$27,900

Repair of truck assemblies requires the placement of the bulkheads for a period of one to four months. There were times during 1998 when three gates were not operable due to failed truck assemblies. The District was fortunate that a flood event did not occur during those critical times, avoiding an increase in flood heights in one of the most sensitive pools in the entire region. Another critical concern during any repair requiring placement of an emergency bulkhead is that another emergency on the same dam could occur while the bulkhead is in use. Such a series of events could lead to loss of Emsworth pool.

During a routine inspection in October 2000 a new problem surfaced. The wheels in the truck assembly for Lift Gate #6 had moved out of position by disengaging from the metal tracks, causing the gate structure to slide against the pier. To prevent further damage to the gate and dam pier, the lift gate was taken out of service. A repair crew jacked the gate upstream and forced the wheels back into the guide track. The bulkheads were removed and the lift gate was operated, but after a few feet of travel the wheels again moved out of the guides. The exact cause of this problem has not yet been determined, and Gate #6 remains out of operation at this time. One such truck assembly that came out of the track, thereby taking the gate out of operation, is shown in Photo IV-2.

To date, all the failures have been on the lower truck assemblies. However, the District has similar concerns about the upper truck assemblies. It can be expected that within the next ten years components of these assemblies will also need to be renovated or failures will begin to occur.

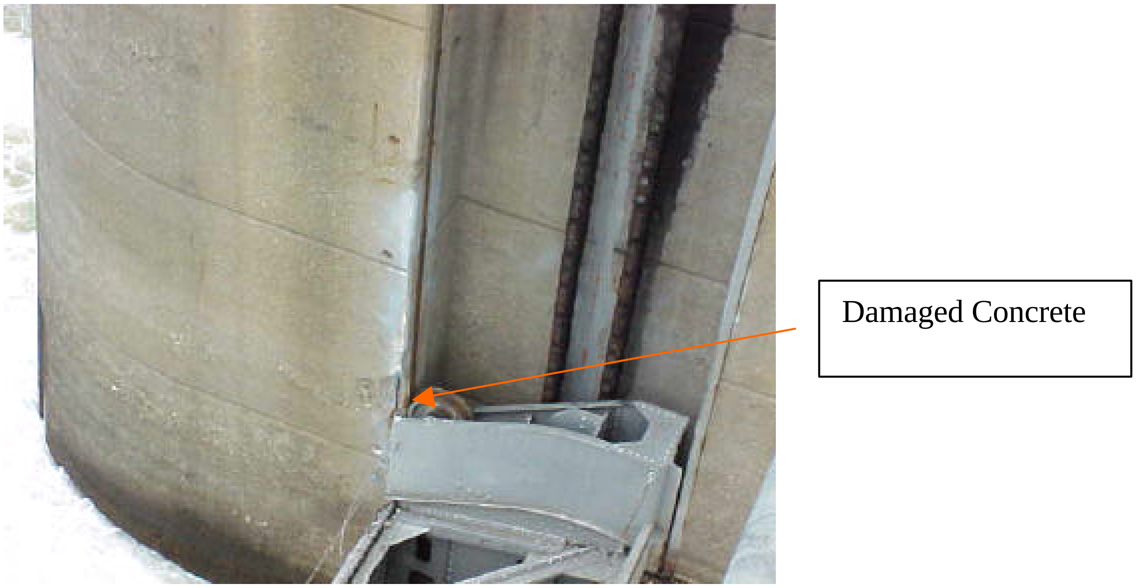

Photo IV-2 - Wheel Truck Out of Track at Pier No. 2. Note abrasion damage to concrete on corner of pier

c. Dam Gate Operating Machinery

The old, outdated and worn chain hoist system and appurtenant mechanical and electrical equipment complicate operation of the dam gates. The major items of concern include the chains, gate machinery motors, and control system.

The large link type chains are difficult to maintain because there is no means of greasing the inner contact surfaces, which has resulted in problems with frozen links that do not wrap properly around the sprockets. Grease is periodically painted on the exterior of the chain to keep it from corroding but the thick grease build up only makes it difficult to inspect for wear and damage. These chains are also corroded and dry, and chains tend to kink and remain kinked even under load.

The gate machinery motors are 15HP wound rotor type, and have shown signs of deterioration. Recent megger readings have shown significant changes in the winding insulation and soon a decision will have to be made as to whether to replace or rewind the motors. Because of the presence of moisture in some of the pier rooms the overall equipment condition varies.

The dam control system, designed to synchronize movement of the two hoist systems on each gate, utilizes programmable logic controllers (PLC's). The PLC system was manufactured by Westinghouse and as with most solid state systems 15 years of age, is now obsolete. The programmable units are very difficult, if not impossible to maintain and repair. The units were designed to be programmed by magnetic tapes, which are no longer available, and exiting tapes are very difficult to program and operate with a laptop computer. In addition, Westinghouse no longer manufactures or supports this equipment, and replacement parts and modules are no longer available. Only repaired and remanufactured parts can be obtained. Parts in need of repair are sent to 3rd party repair shops making turn around time slow and very costly. Because of obsolescence, the advantages of adding or modifying features and parameters of the control system are not possible. This has resulted in a control system that has become inflexible to upgrades and modifications. The entire control system is in need of replacement.

The deck control stations located on the operating piers and used for making local gate operations are in poor condition. The gaskets have deteriorated and the enclosures are no longer watertight. Moisture is causing erratic readings on the LED displays, and the information provided to the operators is no longer reliable.

The gate position sensors are one of the most important components of this control system. Their accuracy is essential since the system relies on this information for synchronizing the two sides of the gate and for providing the signal used to compute the gate height. Synchronization is necessary since the vertical lift gates have two motors, one on each side driving the machinery. The control system must keep both sides of the gate level while raising or lowering. The sensors are located off the machinery bull gear. A gate that hangs up in the guides or has a kink in the chain will not be sensed properly by the control system. For example, while lowering, the bull gear continues turning the sensor even though one side of the gate may not be moving and slack in the chain is increasing. The system does not recognize the need for level correction and the chain continues to go slack until the gate is so far out of level it releases and drops unrestrained. This increases the risk of machinery failure or dropping a gate. In addition, several of the gate position sensor enclosures are bent and not square with the drive pulley. The belts often slip off the pulleys resulting in false readings and alarms. This misalignment has placed additional strain on the sensor shafts, which has resulted in readings that are inconsistent. The published accuracy of the sensors is no longer in tolerance.

The lift gates, operating machinery, and remote controls have become unreliable, so much so that it has become necessary for safety reasons to have the Lock & Dam Operator stationed at the lift gate during operation to visually inspect the operating system and check for developing problems, the most serious of which is due to unsynchronized movement of the two gate chains. Visually attempting to determine the levelness of the gate is difficult, impractical, and costly. The ability of the control system to level the gates is currently compromised. The gates must be level to safely operate the dam gates. Alternative methods of sensing and controlling the gate position must be considered during the design of a new control system.

Before visual inspection was instituted, the system failure caused vertical lift gate #14 to drop twice, in November 1972 and February 1988, requiring repairs that, in 2001 dollars, would equate to $1.1 million and $120,000, respectively. Photo IV-3 shows the broken chain and Photo IV-4 focuses on a damaged truck assembly, both caused by the 1988 event. These events occurred prior to the dedication of operations staff to visually inspect gate operations. Without the close supervision now devoted to gate operation, repeats of these incidents would be a certainty.

Photo IV-3 - Broken chain resulting from dropped gate, February 1988

Photo IV-4 - Damaged lower wheel truck, Gate #14, resulting from dropped gate, February 1988.

The existing dam gate operating system does not take advantage of modern-day technology. Control components designed to accommodate the existing lift gate system would not be adaptable to hydraulic lift gates. The use of hydraulics and solid state controls has become the standard for vertical lift gates and associated control systems. Controllability, flexibility, and diagnostic capabilities are some of the advantages of modern-day control systems utilizing hydraulics and programmable logic controllers. Through this technology, numerous control options including accurate synchronization and dependable information can be provided to the operators to insure safe and reliable gate operations.

The Pittsburgh District has the opportunity of converting the entire out-dated lift gate system to the more modern hydraulic lift technology, which would eliminate recurrent problems with misalignments, breakage of chains with resultant failures that will forever be associated with the existing mechanical driven chain system. The new gate being installed in Gate Bay #7 is a hydraulic lift design. It is significant to note that the hydraulic operating system costs over $200,000 less per gate than a chain gate system patterned after New Cumberland[1] that is more modern than the system at Emsworth. This estimate is based on the cost of the New Cumberland gates, which is very conservative since there are far fewer foundries today that could fabricate the components for the gates. In addition to eliminating all chains, the new gates would be a modern welded design instead of rivets,

[1] New Cumberland Locks and Dam is the fourth project from the head of the Ohio River, located in the Pittsburgh District. This facility was constructed during 1955-1963 and has been operated and maintained since November 1959.

making it both stronger and lighter than the existing gates, and involve better wheel assemblies that utilize two wheels per side of gate instead of four.

d. Scour Protection

Scour holes downstream of the main and back channel stilling basins have been a recurring problem since the dam alterations done in 1937. It is now obvious that the additional hydraulic head of the seven-foot increase in upper pool has created stronger currents than ever suspected on the downstream side of the dam. Significant erosion protection was added during the 1980's rehabilitation in the form of a rock blanket. Damage to this scour protection may lead to erosion of foundation material under the stilling basin and the gated dam superstructure, which could result in lessening of lateral support of foundation piles. Reducing this lateral support could then lead to buckling of the piles and then to failure (movement) of the stilling basin or gated dam sections.

In spite of this significant fortification effort, this rock blanket has not proven very effective. Divers' inspections (1983, 1987, and 2000) and various soundings taken immediately downstream of Emsworth main channel dam have revealed that many of these boulders have been washed away during the past fifteen or so years, leaving gaps exposing lower layers of the blanket. Inspections during 1984 determined the condition of the stone protection near gate bay No.4 failed by displacement, requiring emergency repairs consisting of grout-filled bags. Inspections during 1987 determined stone protection near gate bay No.3 failed by displacement. In addition, areas of missing stone protection, exposed filter fabric, and exposed timber cribbing near gate bay No.14 in the back channel dam have been reported over the years. Divers inspections during 2000 determined an estimated 50% of stone protection has been displaced. Locations were random, but true in all gate bays except No.4 where the grout filled bags have held up well. Missing stone was evident on both dams. The timber cribbing under the dam apron was not exposed due to one row of 5 feet diameter stone still in place along the edge. However, the second row had 50% stone washed away, and it is only a matter of time before the first row of protection follows. Furthermore, evaluation of lockmaster soundings during 1998, 1999, and 2000 indicate significant scouring at a number of locations downstream of the stilling basin.

In general, the extent of scour seems to encroach to less than 25 feet from the dam apron face, with about 1’ to 8’ holes of missing protection at random locations. In some areas closest to the dam apron, one entire row of the massive stones has washed away, leaving only a single row standing against the face. If the displacement continues in these areas, the dam apron and stilling basin will be undermined until the structure fails. Such a failure occurred prior to a 1977 repair of the apron of Gate Bay #3. The apron had been undermined, causing it to crack and displaced by as much as 25 inches. A failed structure will also affect the gated dam structure since they are abutted together. Grout bags installed near gate bay #4 are at risk of being undermined or slumped and have not been tested against current hydraulic design criterion. The current criterion addresses the need to design for all gate operations in relation to various tailwater elevations. All of the aforementioned circumstances signify the need to effectively evaluate the adverse hydraulic characteristics and the potential impacts to the dam superstructure if conditions worsen.

There is a range of possible solutions that could be implemented to provide adequate protection downstream from the stilling basins of both the main channel and back channel dams for the fifty-year analysis period. These measures include:

1. Reconstruct the stilling basin by lowering the floor elevation and modifying its geometry for effective energy dissipation.
2. Place a layer of grout filled bags overtop all of the existing stone protection to prevent scour.
3. Identify and fill scour holes with material as needed.
4. Replace the stone protection with a concrete stilling basin extension that would dissipate energy and prevent scour.

Out of these four possible solutions, the preferred strategy is to construct the stilling basin extension for the length of the back and main channel dams totaling 1,717 feet. In light of the long-term problem and history of remedial measures, this option was chosen based on its design merits of not having to disturb the existing concrete stilling basin while providing the most long-term durability. The design incorporates the strength of concrete along with an optimum configuration of dissipating energy to maintain uniform flow patterns. More information on this feature is provided in Appendix A, Section A.4.

e. Dam Concrete

While the concrete in the dam piers is generally in good to fair condition, it shows advanced deterioration in localized areas. The top surface and areas on the vertical surfaces of Piers 6, 7, 8, and 9 of the main channel dam, and Piers 12 through 16 of the back channel dam contain deteriorated concrete in poor condition. The top surface deterioration consists of fine-to-wide random cracking, medium scaling, and small spalling, predominately in the downstream section of the piers. Spalling is generally adjacent to the girder supports. Many of the seats are corroded, and staining can be seen on the horizontal and vertical surfaces of some piers. Corrosion of the anchorage is a possible cause of the spalling. The damaged areas on the vertical surfaces exist on the land and river sides of the piers and extend 8’ to 10’ below the top of the pier. The concrete in these damaged zones is considered to be in an advanced stage of deterioration. Also, concrete has deteriorated to such a degree around the wheel guides of Gate Bay 14 that the vertical-lift gate has become dangerous to operate for fear of failure. Photo IV-5 shows a dramatic example of damaged concrete on one of the main channel piers.

Photo IV-5. Heavy Cracking with Efflorescence on Downstream Pier Stem.

f. Service Bridges

In February/March 2001, Tri-State Engineering, Inc. inspected the Emsworth Main Channel and Back Channel service bridges as part of the COE Bridge Inspection Program. The inspection reports can be found in Appendix A, Section A.5. The inspections determined that the condition of the major components is similar for both bridges and is generally good. Addressing certain deficiencies can extend the lives of the bridges at least 50 years. The areas of concern are the concrete bridge deck, the locomotive crane rails, the bridge bearings, and the conduit bracket tray.

The top of the concrete bridge deck slabs is weathered and exhibits numerous patches, map cracking, pop-outs, spalling and areas of delamination. The slabs appear permeable to water at places of delamination. The bottom of some slabs exhibits efflorescence with water seepage and areas of exposed rebars. It is recommended to remove the concrete slabs and recast a new deck.

The crane rail system was designed to allow the rail to expand and contract independently from the service bridge. Prior to the Major Rehabilitation it was noted that corrosion between the rails and clips and between the rails and splice plates had been preventing free movement of the rails. The system was disassembled, cleaned, painted and reassembled to restore it to the design condition. The recent inspection revealed that heavy rusting has reoccurred and the resulting binding is causing bent splice bars and sheared off rail clips. It is recommended that the rail plates, clips, splice bars and track bolts be replaced.

The bridge bearings exhibit light to moderate rusting of both the top and sole plates which is preventing proper movement at the expansion ends. At several locations the anchor bolts are bent and tilted. The gaps between the piers and the spans vary considerably due to the malfunctioning bearings and the lack of crane rail movement. It is recommended that the bearings be replaced.

The conduit bracket trays are located underneath the pedestrian walkway and carry the electrical conduits across the dam. The trays are typically rusted throughout and need to be replaced.

g. Summary

As described above, Emsworth gates and gate operating system are old and in many respects obsolete. The District has had to deal with numerous instances during the 1990's where one or more gate has been inoperable at a time. Without major work, this situation can only be expected to become worse. Many of the potential problems can only be expected to occur more frequently, or to much more dramatic degrees during the analysis period. Events that could likely occur in the near future include failure of truss assemblies or mechanical hoist systems or even displacement of the gated dam superstructure itself. Occurrences of events involving outages of more than one gate at a time at either dam can only be expected to increase if problems worsen. These events could then lead to loss of Emsworth pool, a critical pool in the Ohio River Navigation System and one that supports numerous regional industrial and recreational activities. Ensuring that there is no disruption to the Emsworth pool is clearly in the best interest of the nation and southwestern Pennsylvanian area. Furthermore, verifying that Emsworth Dams can be restored to provide service well into the millennium will support on-going studies of larger locks in the Upper Ohio region.

The major opportunity addressed by this study is the chance to eliminate all problems and modernize old components such that safe and reliable service can be ensured for at least another fifty years.

2. STUDY OBJECTIVES AND CONSTRAINTS

The objective of this Major Rehabilitation Evaluation Study is to identify the most cost effective and efficient way to ensure safe and reliable operation of Emsworth Dam for a 50-year study period (2007-2056). The initial year represents the first year that a rehabilitation project could be completely operational, and the end date represents the fiftieth year of the analysis period. The recommended alternative will consist of replacement and repair activities and non-structural operational measures as appropriate for critical dam components.

There are two analytic constraints regarding future plans:

- All alternatives maintain the existing level of hydraulic (water flow) capacity through Emsworth Dam. This constraint is vital to prevent any increase in flood frequencies or heights at the downtown "point" of Pittsburgh. Consideration of alternatives that are potentially of lesser cost but which lessen the hydraulic capacity were not considered.

- All alternatives will accommodate underflow operation of gates As previously noted, the gates were converted to underflow operation only in 1973. The gates were modified primarily through removal of the top overflow plate. There is no advantage to reinstating overflow operation of any Emsworth gates. In addition to the structural advantages noted previously of underflow vs. overflow operation (i.e. lesser loading on gate members and lower tendency for truss members to corrode), underflow also provides a greater degree of re-aeration. The reason for this is the relatively high dam gate sills.

SECTION V. PLAN FORMULATION

Alternatives considered in this report conform to general requirements in EP 1110-2-500 (noted as EP) and Planning Guidance, ER 1105-2-100 (noted as ER). The Baseline condition as defined in the EP assumes that the project will be operated in the most efficient manner possible without the proposed rehabilitation. This definition closely parallels that of the "Without Project Condition" defined in the ER. The Without Project Condition is defined as the most likely condition expected to exist in the future in the absence of a proposed water resources project. The water resources project for this study is the rehabilitation. In this report, the term "Without Project Condition" is used to describe the best alternative that does not include any Major Rehabilitation (as opposed to the word "Baseline"), and is the condition against which rehabilitation alternatives are compared. Incremental benefits of rehabilitation must exceed the incremental costs over the Without Project Condition before the alternative can be recommended for implementation. All alternatives will automatically include any work currently obligated, specifically, the replacement of Gate #7 with a hydraulically operated vertical lift gate.

In order to fully assess the most-likely probable future Without Condition, four types of alternatives are discussed in this report. In lieu of funding for a Major Rehabilitation, that alternative which is most cost-effective will be considered the most-likely Without-Project Condition. Under any of these alternatives, it is assumed that Operations and Maintenance (O&M) funds would be used to accomplish future repairs.

This section begins with a general formulation of basic alternatives (features of both the Without- and With-Project plans). The methods of engineering analysis used to assess hazard rates and probabilities of failure are described, with liberal references to the General Engineering and Reliability Appendix (Appendix A) followed by analytic results, as well as for components not subject to this type of analysis. Economic modeling methodology to estimate costs that may result due to deferring work on critical dam gate and scour protection components is described. All alternatives are evaluated considering economics, environmental and real estate factors. The section concludes with a recommendation for Major Rehabilitation.

1. WITHOUT PROJECT CONDITION

As described above, the Without Project Condition is the most efficient manner to operate Emsworth Dam without any scheduled rehabilitation. Following the logic presented in the EP, four alternative strategies were formulated that would maintain operation of Emsworth dams throughout the analysis period. These four alternate strategies are presented here in the order of scheduled work requirements-- i.e., from less-scheduled work to a highly intensive scheduled maintenance program. The alternative with minimal scheduled work requirements is a "fix-as-fails" (or minimal investment strategy) strategy that would only replace or repair components after a failure, with the exception of the replacement of Gate #7 which is currently scheduled to be completed by 2003. This scenario is the starting point of analysis. The other three alternatives include two that are defined in the Rehabilitation EP, termed "Scheduled Repair" and "Advanced Maintenance", and a third that is a hybrid of these two alternatives. All alternatives are described below.

The major consequence of concern in all of the candidate Without Project Condition alternatives is the possible loss of Emsworth pool. Each dam is equipped with only one bulkhead assembly for use at one gate during emergencies, such as after a failure of a gate component that renders a gate inoperable, or for scheduled inspections and non-emergency work. It is anticipated that these bulkheads can be placed in an emergency to avert any pool loss. However, pool loss could result if there are failures while the only bulkhead assembly is in use at another gate bay. Furthermore, periodic inspections can be made to a maximum of one gate on the main and back channels at a time, since bulkheads would need to be placed.

A loss of Emsworth pool would consist of a drawdown of the upper 6.8 miles of the Ohio River, the lower 6.7 miles of the Allegheny River, and the lower 11.2 miles of the Monongahela River by approximately ten to eleven feet to elevation 698 at Emsworth Dam, the elevation of the Emsworth dam gate sills. This would effectively close the navigation system on the Upper Ohio and Lower Monongahela and Allegheny Rivers and adversely impact several municipal and industrial water intakes. Economic impacts of these potential impacts are discussed further in Section VII.

a. Fix-As-Fails

As the name implies, repair or replacement of components would be made only after failures. In the sense of scheduled work, this alternative represents a "minimum" investment strategy. In the fix-as-fails alternative, inspection of dam gate components usually occurs only during periodic inspections (every five years or so) or in response to apparent malfunctions. Divers would inspect the scour protection only if there is evidence of additional damage to the underlying concrete or stone blanket, portions of which have already been displaced. These assumptions are accounted for in estimated annual future ordinary operations and maintenance expenditures.

Various scenarios under this alternative and all other Without Project Condition alternatives involve potentially extensive damage to the entire gate, including the structural truss members and operating equipment. Given this event, there are several possible replacement strategies. One would be to replace in kind, and maintain the chain lift and independent motor lift technology. Another would be to use a more modern chain lift system, such as was used at New Cumberland L/D at r.m. 54.4 on the Ohio River. Those gates only involve one chain and appurtenant motor system. A third option would be to use the hydraulic lift technology similar to the gate being used to replace Gate #7. The replacement-in-kind option was eliminated from consideration because the components are no longer manufactured. There would be an excessive cost to fabricate new components. The choice between the more modern chain system and the hydraulic system was based on cost. The hydraulic gate would cost a minimum of $200,000 less than the chain-hoisted gate. Therefore, the only gate replacements considered are of the hydraulic lift type. Other scenarios that involve relatively minor damage only involve replacement of the affected equipment and therefore maintain the chain hoist system.

Risk costs due to component failures were estimated using reliability results and consequences of component failures as described in Section VII and Appendix B. The expected damages resulting from loss of pool will be estimated through use of the Life Cycle Lock Model described in Section VII and Appendix B.

b. Scheduled Repair

This alternative as described in Corps regulations is designed to make preparations to lessen economic impacts by reducing the time of expected project service disruptions. Lessening of the likelihoods of failure is not addressed, only reaction times. This could be done, say, by stockpiling parts subject to failure so that repairs could be made as quickly as possible. Alternatively, or in concert with stockpiling parts, some repairs or other preparations may be possible, including emergency procurement measures that have the similar effect. The key factors to consider in evaluating this type of measure is implementability and the impact of such stockpiling or other process would have on loss of pool duration. These measures would seemingly have small if any impact on actual construction or fabrication costs. However, any lessened duration of pool loss could incur significant benefits. The cost of purchasing structural components, storing, and any other preparatory actions would need to be more than counterbalanced by reductions in expected consequences of failure.

For Emsworth Dams, one possible action under this alternative would be fabricating and stockpiling truss members. This could reduce the time to reconstruct truss members given a gate-failure event. However, as indicated for the fix-as-fails condition, it is expected that the necessary repair following a truss failure would also involve mechanical and electrical machinery. As discussed above, given the need to replace a gate and hoist system that fails, the same hydraulic lift gate would be installed. Furthermore, the time to reconstruct a gate is not as important as is the time required to restore any loss of Emsworth (whether through setting the emergency bulkhead or, if already in use, constructing a temporary sheet pile structure). For these reasons, stockpiling of gate components would not be effective and was dropped from further analysis.

Given the importance of preventing loss of Emsworth pool, constructing and storing one additional bulkhead assembly for either or both the main channel or back channel dams could prevent loss of pool in cases of gate or dam failures where the original bulkhead was already in place. This option will be carried further for economic analysis.

Other practical options are to either stockpile sheet pile material used to close off a gate bay when a bulkhead is not available, or develop a procedure to obtain such material as quick as possible on demand. Either strategy would lessen the duration of pool loss given that the event occurs. The procurement option is preferred due to the low cost. Although this option is not costed out, it was incorporated into all cost estimates that consider costs due to failed components. Another possible option is to stockpile one or more truck assemblies to accommodate future outages. However, since the chances for a truck failure to cause loss of pool directly are extremely small, a bulkhead would be set only when necessary, that is, during actual work. Therefore, there would be no apparent benefit of stockpiling trucks.

More flexibility may be possible with other components (electrical & mechanical, dam concrete, and service bridge). Those repairs could be made on an as-needed basis as conditions become apparent during inspections. One possible strategy considered was the stockpiling of chain components or entire chain assemblies. As with gate truss assemblies, this strategy would have negligible if any impact on duration of loss of pool, as it is placement of bulkheads or construction of sheet pile sections that could impact durations.

c. Advanced Maintenance

The advance maintenance strategy is intended to reduce the occurrences of failures that could lead to loss of pool. There are several intensities of work possible under this philosophy, which can be generalized as non-structural and structural in nature. One non-structural strategy would be to increase the intensity of inspections of components to try to head off failures before they occur. Structural measures include replacing portions of the existing gates or entire gates, as is being done with Gate #7.

Increased inspections of some components such as truss members would be of questionable effectiveness in reducing likelihoods of failure due to existing poor condition or difficult accessibility. Many truss members have already corroded to dangerous levels, and truck assemblies continue to fail at alarming frequencies. Inspection of chain hoists would also be problematic. Divers' inspections would be required to monitor the scour blanket, which already is in very poor condition. These inspections would have very little impact on failure probabilities. Increased inspection of electrical and other mechanical equipment would have minimal impact on reducing the likelihood of the key item of concern, loss of pool. Therefore, the increased inspection strategy is hereby dropped from further consideration.

Existing truss structures are not compatible with hydraulic lift gates. It would not be possible to maintain the trusses and install new mechanical and electrical components that are being used in Gate #7. Therefore, any piecemeal replacement of gate parts would maintain the old chain hoist technology. Furthermore, maintaining the old chain hoist technology would not eliminate the potential for future gate malfunctions, including dropping gates. This type of alternative is not considered practical and is therefore dropped from the analysis.

For reasons described previously, any gate replacement would involve new hydraulic lift technology, including the Sidney (tainter) gate. Twelve vertical lift gates and one Sidney gate would be replaced. New hydraulic gates could be installed from Operations and Maintenance funds at a frequency of about one gate every two years.

d. Hybrid Repair/Maintenance

In theory, this alternative could involve the best of the two options discussed above in some sort of hybrid plan that lessens (not necessarily eliminate) both the chances for failure and the duration of outage given a failure event.

2. REHABILITATION ALTERNATIVES

Two Major Rehabilitation alternatives were considered, one where the work is performed as soon as practical and another that defers some or all work. Funding for all rehabilitation work would be shared equally between the Federal "Construction General" (CG) Account and the Inland Waterways Trust Fund.

a. Immediate Rehabilitation

This option involves up-front and total rehabilitation and modernization of all eight components described in the Problems and Opportunities section beginning in FY 2003. This alternative would involve up-front replacement of twelve vertical lift gates and the Sidney gate with gates using hydraulic lift technology, replacement of all scour protection, and repairs to the dam concrete and service bridge.

b. Scheduled Rehabilitation.

This strategy involves the same work as in the immediate rehabilitation alternative, but considers deferring some or all work if economic benefits are greater than immediate deployment. Depending upon the resulting timing, some of this work may need to be performed under Operations and Maintenance funds if "bundling" of work to meet rehabilitation requirements is not possible. All Scheduled Rehabilitation alternatives have an element of risk or cost as described for the Without Project Condition alternatives to the extent that components may fail before the scheduled work

SECTION VI. ENGINEERING ANALYSIS

1. METHODS OF ENGINEERING ANALYSES

Major components cited in the Problems and Opportunities paragraphs (Section IV.1) were evaluated to estimate the projected integrity throughout the planning period. For gate components, the results of these analyses were annual probabilities of unsatisfactory performance. These probabilities were in turn fed into the economic analyses. Reliability techniques that comply with Corps guidelines were used to estimate these probabilities through calculation of hazard values. Engineering judgment was used to evaluate probabilities of several failure modes for scour protection. Also, the impacts of repairs on these probabilities had to be determined. In most cases, if components were replaced, they were assumed not to fail again during the planning period.

Up to this point, the term failure has been used in a generic sense to denote nonconformance to some defined criterion such that a component can not perform its intended function. Probabilities of unsatisfactory performance were used as input to economic models to facilitate evaluation of various maintenance and repair strategies of these components, ranging from doing nothing and purely reacting to failures after they occur, to scheduled repairs and replacements designed to prevent any failures. To accomplish this end, specific failure modes must be defined and, if more then one is foreseeable such that any of multiple repair scenarios may be required, all modal failure probabilities determined. All components except scour protection, dam concrete and service bridge components were evaluated in this manner with reliability analyses. Probabilities of failure were evaluated for scour protection in a less formal fashion. The dam concrete and service bridge components were evaluated without economic analyses. Failure modes for specific components are discussed below and in subsections dealing with the engineering results.

The discussion below describes the general methodologies used for both reliability and non-reliability evaluations. Processes are described in more detail in Appendix A, Section A.1. Readers not interested in analytical details should skip the following subparagraphs. Results of the engineering assessments are summarized below in subsection 6.

2. COMPONENTS ANALYZED WITH RELIABILITY TECHNIQUES

Reliability can be defined as a measure of safety or assurance of adequate performance of a structural component. Reliability analyses can account for uncertainty both in strength or other properties of structural members. Structural strength properties may also be a function of time, usually in degrading fashion. Structural integrity is adversely impacted by factors including structural deterioration of members due to factors including corrosion and fatigue.

The output of reliability analyses are hazard rates. In mathematical terms, the hazard function represents the rate of change of the conditional probability of unsatisfactory performance in a particular time period, where the "condition" is that the component survived or performed adequately up to the beginning of that time period. The time period used in all evaluations is 1 year. An aging structure is typically characterized by an increasing hazard rate. Calculation of hazard values required identification of potential failure modes and the associated "limit states", which are mathematical expressions defining the necessary condition linking forces and resistances such that adequate performance would result. Annual hazard values are probabilities that these limit states are violated. These values are utilized as probabilities of failure in economic models.

Engineering reliability was used for evaluation of the following components of the main and back channel vertical lift gates: truss assemblies; truck assemblies; and appurtenant mechanical and electrical systems. For each of these components, the general procedures and analytical models are summarized below. Results are presented in Section V.3. This material is covered in more detail in the Appendix A, Sections A.1 and A.2.

a. Gate Trusses

The condition and performance of the vertical lift gate truss assemblies are time dependent since corrosion degrades the strength of the gates by reducing the dimensions and the cross-sectional properties of their members. (Corrosion is considered for truss and plate members in the splash zone, only.) The existing condition of the trusses was established by structural analyses that considered both the structural integrity and stability of all structural members. First, structural analyses were performed in order to:

- Identify significant loadings,
- determine a subset of eight truss members critical to the functioning of each assembly, and
- Determine the maximum amount of corrosion that these critical members could sustain before failure would occur.

These analyses considered both truss members and skin plates.

One limit state was determined for each of four failure modes -- tension, compression, flexure, and buckling. For each mode, only two states are possible, either "no- fail" or "fail". The limit states for buckling and exceeding ultimate strength were established from American Institute of Steel C Load Resistance Factor Design (LRFD) Specifications for Structural Steel Buildings. The structural analysis program selected to assess the performance of the vertical lift gates degrading in time was STAAD/PRO commercially available structural program STAAD/PRO (Research Engineers, Inc.). Hazard values were determined for three conditions corresponding to gate configurations. Two of these applied to members subject to corrosion (i.e. in the splash zone), the third for members out of the splash zone. All hazard rates for each gate configuration and for each mode were combined to produce one hazard value for critical truss members.

Many loads were considered in structural analyses, including:

- structure weight,
- "live" loads from mud, ice and other debris,

- "drag" due to friction of wheels, trucks and bearings,
- barge and ice loads, and
- others including seismic and wind loads.

Loads that were considered critical include the weight of the gate, or gravity load, "drag" (due to friction of the wheels, trucks and bearings), hydrostatic, and thermal. Barge and ice loadings were considered in analyses of non-corroded structures (i.e. members not in the splash zone), only, along with dead and hydrostatic loads. Potential failures due to fatigue, deflection, and rivet corrosion were also considered, but were not determined to be significant factors in terms of reliability.

Corrosion rates for the lower truss and plate members in the splash zone were described by normal distributions. The mean and standard deviations were determined based on the results of ultrasonic measurements taken of various members taken in 1998 to determine remaining material thicknesses. The mean and standard deviation for single-sided corrosion for lower truss members are 0.112" and 0.040", respectively.

Reliability models were developed for each critical member using Excel and the add-on application @Risk. @Risk facilitates the Monte Carlo simulation requirements for these models. Models incorporated (1) original member thicknesses, (2) the critical member thickness, and (3) probabilistic corrosion rate, such that the probability in a given year that the remaining thickness is less than the critical value could be calculated. This condition by definition is violation of the limit state and thereby estimates the probabilities of failure. Calculation of hazard values follow, as documented on pages in Appendix A, Section A.1.

The critical members are treated as independent components of the vertical lift gate, since a failure of a critical member causes the gate to collapse. System redundancy does not exist past the point of a critical member failure since redistribution of load cannot occur. As a result, the critical members are treated as independent components in a series where the system reliability is a product of the critical member reliabilities. Failure rates for individual components were combined statistically to provide "system" failure probabilities, or the probability that the gate fails in any given year. Details of system hazard value calculations are provided in Appendix A, Section A.1.

b. Gate Truck Assemblies

The reliability models and procedures for trucks are similar to that for truss members, except for the truck link reliability model. Failure for a truck link occurs when the corroded cross-section area is equal to the critical cross-section area. Corrosion rates for the links and support brackets were determined based on data for truck links that actually failed and were removed from service as a result of severe corrosion. The mean and standard deviation values for the corrosion are 0.322" and 0.058", respectively.

A separate structural model was developed to investigate the time-dependent performance and failure mechanism for the truck wheel assemblies and their housing. The results for the reliability model for the trucks are probably overly conservative, since the truck links and their assemblies have failed or were removed from service due to severe corrosion eight (8) times in the past 3 years. Vertical lift gate No. 1 is experiencing a recurring problem with the truck assemblies within 1-½ years of repair.

c. Gate Operating System

The dam gate operating system consists of both critical mechanical and electrical components. These components together form the electrical and mechanical gate operating system. Satisfactory performance of both of these systems is necessary for satisfactory performance of dam gate operation.

The major components of the system were reviewed to identify the critical components that would potentially cause unsatisfactory performance of the gate operating system for one gate. All components of the operating system, including the electrical distribution and mechanical subsystems, must function properly for the dam gates to operate. These subsystems were analyzed separately.

From a system perspective, the model of the gate operating system is a series of the electrical and mechanical subsystems. The results were then coupled to attain reliability and hazard function values for a complete dam gate operating system. The reliability analysis of the each subsystem was performed based on the guidelines provided by ETL 1110-2-549, Engineering and Design, Reliability Analysis of Navigational Lock and Dam Mechanical and Electrical Equipment, 30 November 1997. The following describes the assumptions made in the analysis and the procedures followed.

The electrical subsystem comprises of critical electrical components as indicated in the single line and reliability block diagram (RBD) (Appendix A, Section A.2). These critical components are modeled into a series block diagram and represent the analysis for one gate. The electrical system begins at the incoming service, which also feeds the lock.

The electrical RBD does not completely reflect the single line and was based on the following assumptions:

- It is highly unlikely that both the commercial and standby power systems would fail at the same time. Power is considered always available and reliable. Therefore, the commercial power and standby generator were not evaluated.
- The electrical system contains several critical components such as circuit breakers and fuses. These components are easily replaced and readily available and therefore not evaluated.
- The hydroelectric generator is no longer utilized and also not included in the RBD.

The brakes are considered mechanical equipment and not included in the electrical analysis.

Based on these assumptions, the critical components reduce to feeders installed in conduit, switchgear, and a power panel. From the power panel, components include the dam feeder, transfer switch, controllers (2), motor feeders (2), motors (2), limit switches (2) and sensors (2).

The critical components of the mechanical subsystem for one lift gate's machinery are an electro-mechanical brake, coupling, worm gear, shafts (3), spur gears (4), bushings (7), shafts (2), chain sprockets (2), and a lift chain. The steel support structure, chain dead-end, and various nuts and bolts were not evaluated. The analysis model takes into account the need for two sets of dam gate lift machinery.

The analysis of the dam gate machinery includes critical mechanical components as indicated on the mechanical RBD. The mechanical RBD illustrates a series block diagram of critical components for one dam gate lift machinery. Operating a dam gate requires two sets of lift machinery.

For both the electrical and mechanical analysis, failure rates were selected from various data sources including the ETL, Reliability Analysis Center, and the previous completed Studies. The characteristic life parameter was determined from the failure rate data using the method presented in the ETL. The shape parameter values β were selected from the Weibull database and previous studies. The calculated results for the system reliability, probability of failure, and hazard rates for the dam gate operating system are shown in Appendix A, Section A.2.

3. COMPONENTS CONSIDERED WITHOUT FORMAL RELIABILITY TECHNIQUES

a. Scour Protection

Although hazard functions were not developed for scour protection, an economic analysis was performed using engineering judgment as to potential consequences and the associated likelihoods of occurrence if this feature does not contain foundation material as intended. Events of interest concern impacts to the foundation material and structures that are meant to be protected, namely the stilling basin and gated dam superstructure. Three types of failure and repair strategies were developed and probabilities of occurrence annually throughout the analysis period were determined. The least severe state is localized scour (loss of foundation material) without any movement of the stilling basin or gated dam superstructure. Next in severity is the state where the erosion of foundation material leads to buckling of the pile supports for the stilling basin such that there is deflection of the stilling basin. The most severe consequence is where the erosion causes deflection or movement of the gated dam such that the dam is breached, resulting in loss of pool.

Annual probabilities of failure of each of these three events were determined by estimating the average number of occurrences per year based on number of gate operations, variable flow conditions, and an estimated conditional probability of occurrence of each event per gate operation under each of the flow conditions. Based on the average annual number of occurrences of each event, failure probabilities were calculated for use in economic modeling.

b. Dam Concrete

Concrete in the piers and service bridge slabs were evaluated based on observations made by District and Architect/Engineer personnel during recent periodic inspections.

c. Service Bridge

The primary method of analysis of the expected future condition for both service bridges is consideration of information and data contained in Appendix A, Section A.5. Conducted by an Architect/Engineer specifically for this study, it was completed in March 2001. This information was supplemented by other information generated during inspections by Pittsburgh District and Federal Highway Administration personnel during the 1980s and 1990s. These bridges are inspected by Pittsburgh District engineering and operations personnel during periodic inspections, which take place every five years. The FHA inspected and evaluated both bridges in 1996. Based on all of this information, potential consequences that could occur if no work is taken to address the problems are indicated.

4. EVENT TREES

Event trees were developed for all components except the service bridge and dam concrete. This subsection provides a general discussion of event trees. Actual event trees for all engineering components are discussed in Appendix A. Event trees address in probabilistic terms the repair or replacement actions that would be necessary for components and all associated costs, including the repair or replacement of the component and economic consequences to industry. Potential industry consequences for this study would be due to loss of Emsworth pool and are addressed in Section VII-2 .

To demonstrate, a portion of the event tree for the mechanical system is shown in Figure VI-1. (The full event tree appears in Appendix A, Section A.2.) Each branch represents a possible course of action based on member performance, and therefore will have a probability of occurrence associated with it. For components with time dependent hazard functions, reliability will decrease with time if no failure occurs (and failure probabilities would increase). If a component fails, and is repaired, the hazard function is usually preset back a number of years using the appropriate hazard function to reflect an improved condition. The reliability of a component that is replaced is normally reset to 1.0 (equivalent to a negligible probability of failure) throughout the remainder of the analysis period.

In Figure VI-1, the top branch represents the probability of satisfactory performance (or non-failure) for the year represented. The total probability of failure in this example is 0.375%, or less than 4 in one thousand for the year in question. This probability value was calculated as the hazard function value for the year in question.

The component represented in Figure VI-1 may fail in either of two ways, therefore the failure branch separates or manifolds into additional branches, each one representing a potential failure "event". The top sub-branch represents the less severe event, where the mechanical system is repaired, occurring an estimated 95% of all failure events. The probability of a repair would be calculated as (0.00375)*(0.95), or about 0.356%. The bottom branch represents the more catastrophic and costly event, where the mechanical system would need to be replaced, only occurring about 5% of these events. The probability of this event would be 0.019%

The sum of the probabilities for all possible outcomes or consequences of any event must always be unity (1.0) for all years. They may or may not change over time, even for components with time-dependent hazard functions. This is so because the probabilities of consequences are not necessarily directly tied to the component hazard function.

Event trees for all components were input into the economic analysis and combined into systems to determine justification, which is described in Section VII.

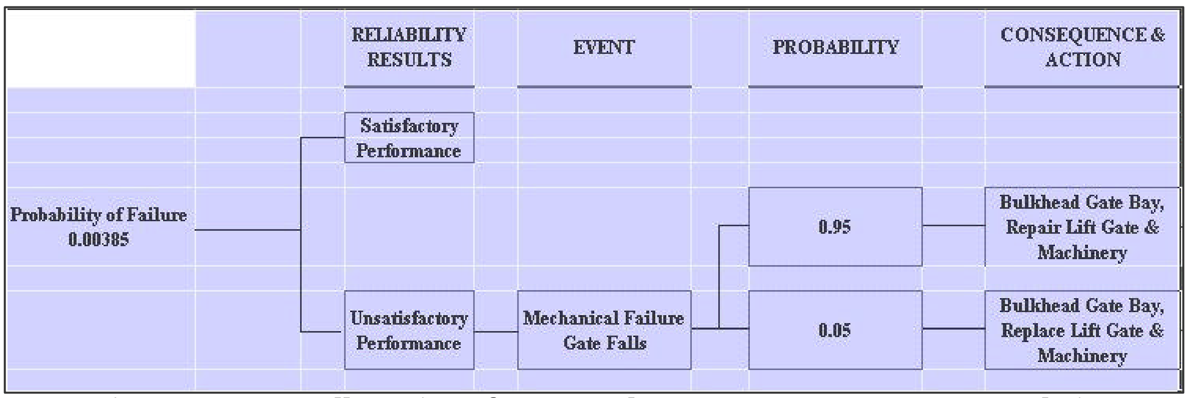

Figure VI-1. Small portion of Emsworth Dam Event Tree For Gate Chains

5. BANK STABILIZATION CONCERNS

The Emsworth pool has over 50 miles of the most highly developed shorelines in the Pittsburgh District. These shorelines support many commercial and recreational river related facilities, see Table III-4 and III-5 respectively, along with a significant network of transportation infrastructure.

In the event that the Emsworth pool was to experience a rapid drawdown situation due to gate failure, the stabilizing influence of the water pressure on the banks would be lost. Uniform deposits of low-permeability clays and silts are predominant in this region and are particularly susceptible to drawdown induced bank distress. Unless pore pressures within the bank can dissipate quickly, the slope is subjected to higher shear stresses and potential instability.

With the loss of pool for an extended duration (8 to 10 weeks), the changing flows within the new pool create additional risks. Low river stage conditions can accelerate scouring of the toe of the banks through different currents, eddies, turbulence, and increased stage fluctuations. The loss of any additional toe material from riverbanks already distressed by drawdown will significantly increase the probability of bank instability.

The Pittsburgh District has experienced the loss of pool behind navigation dams in the past. Specifically, the Maxwell pool (Monongahela River) was lowered in a controlled manner in 1990. The Maxwell pool was dropped 17 feet in approximately 7 days and experienced one recorded failure of significance. Approximately a 150-foot reach of a riverside park dropped 4 feet. Bank instability in this case was minimized because the pool was restored within 3 to 4 days following the lowering of the pool. Although there is limited experience with the impacts of loss of pool conditions, empirical relationships between the changes in shear strength and pore pressures indicate that stability problems affecting the riverbanks, river facilities, and the transportation infrastructure are inevitable, if the Emsworth pool was down for an extended period.

6. HAZARD RATES AND FAILURE PROBABILITY RESULTS

Critical members for dam gates were analyzed for reliability. Results of all reliability analyses are presented in Table V.1. These results are discussed in detail in the following subsection. including a discussion of event tree formulation. All event trees developed for engineering analyses can be found in Appendix A as referenced below. Probabilities of failure and potential consequences of all events were fed into the economic analyses described in the next subsection 5. Economic simulation models were required to account for interdependency among the components described in this subsection.

Table VI-1 Hazard Rates for Dam Components

Probability of an Unsatisfactory Performance, Occurring Within 365-days for Given Years and Given Components

Year	Truss (gate blows)	Chain (gate falls)	Truck (gate stuck)	Dam Gate Operating Machinery (1) (gate stuck)	Scour Protection
2000	0.0932	0.0039	0.0970	0.0781	0.1890
2010	0.1210	0.0039	0.1340	0.1219	0.1890
2020	0.1396	0.0039	0.1821	0.1759	0.1890
2030	0.1517	0.0039	0.2334	0.2384	0.1890
2040	0.1610	0.0039	0.2777	0.3071	0.1890
2050	0.1695	0.0039	0.3063	0.3797	0.1890

a. Gate Trusses

The primary event causing gate failure is compression or flexure failure of one or more of eight critical truss members in any vertical lift gate. Failure of a truss system would be instantaneous and dramatic. The resulting damage would almost certainly affect much more than just the steel truss members, especially the hoist chains, sprockets, and associated mechanical and even the electrical equipment. Therefore, the consequence of this event is total gate replacement. As discussed previously, given the requirement for a new gate, the economical choice is a new hydraulic lift gate. Therefore, all repairs of gates that fail structurally consist of new hydraulic lift gates. Hazard values representing annual probabilities of structural failure are shown for various years in Table V-1 under "Truss". These values increase over 80% in fifty years, from 9.3% in 2000 to almost 17% in 2050. More detailed results are provided in Appendix A.

Stopping flow through a failed (open) gate could take from several hours while a bulkhead is installed, or, if a bulkhead is not available, up to seven weeks to install a sheet pile cofferdam. In the former case, there is no pool loss. In the latter case, construction of the sheet pile structure could not begin until the pool falls to the level where flows are low enough. This would take around five days or so, depending upon the flow in the river at the time of the failure. (At low flows, the pool loss would be quick and uncontrolled, at higher flows, the pool could be lowered in a controlled manner.) After the sheet pile structure is constructed, it would take another five days or so to regain the normal pool elevation, again depending upon the flow in the river. Therefore, the total duration of pool loss would be about sixty days. This duration also takes into account the time for emergency procurement of the sheet piling.

b. Gate Truck Assemblies

Only one general failure mode is considered for truck assemblies. Such a failure would involve the links and supports for the wheel assembly that keep the wheels in the tracks. The hazard values in Table V.1 under “Trucks” account for all events that lead to a truck becoming disengaged from the track and rendering the gate inoperable. These values increase dramatically from just under 10% in 2000 to over 30% in 2050. Details are provided in Appendix A.

Repairing or replacing damaged links and supports would require placement of bulkheads for a period of three months. Repairs would be deferred if the bulkhead is already in use. Failure of any truck assembly would not directly lead to pool loss, but any other failure of a gate or gate operating equipment (see next section) while a truck is being repaired could lead to pool loss.

c. Dam Gate Operating Systems

Electrical/mechanical systems are the basic electrical wiring and parts and the machinery that provides power to move the gates. In general, these systems are highly reliable and the consequences of failure are less severe than failures of other components. The probability of failure in the year 2000 was estimated at 7.8 percent. However, 89.5 percent of these failures would be minor (first three columns below), involving no pool loss and repair costs that average about $100 thousand. Major failures such as wedged or dropped gates are more serious and could require the use of the emergency bulkhead for repairs. However, it was assumed that these repairs would be deferred until the emergency bulkhead became available, if the failure occurred while the bulkhead was in use elsewhere. Failure probabilities for some yearly values are shown in Table V-2. Details on the development and results of the reliability analysis are provided in the Appendix A.

Table VI-2 Dam Gate Operating Failures
Event Failure Probabilities

Year	Replace/Repair Component ($40k)	Replace/Repair Component ($100k)	Minor Overhaul ($680k)	Major Overhaul ($1,100k)	New Operating System ($2,183k)
2000	0.0527	0.0166	0.0059	0.0023	0.0006
2010	0.0823	0.0259	0.0092	0.0035	0.0009
2020	0.1186	0.0374	0.0133	0.0052	0.0014
2030	0.1608	0.0507	0.0180	0.0070	0.0018
2040	0.2072	0.0653	0.0232	0.0090	0.0024
2050	0.2562	0.0807	0.0287	0.0112	0.0029

d. Chains

The probability that a chain would fail, dropping the gate, was based on the historic rate of failures between 1972 and 1988 when two instances of chain failures resulted in the gates being dropped. The probability, expressed on a per gate basis, was 0.39 percent. Since the 1986 failure, observers have been stationed to monitor all gate lifts. If problems, such as kinking, are observed, then the operation will be stopped and the operation will be attempted at a different gate. This has tended to reduce, although not eliminate, the probability of chain-related failures. On balance, it was expected that the probability of failure would remain constant at 0.39 percent over the next 50 years, provided that observers are there to monitor the situation. The additional man-power costs were factored into the analysis.

The time required to install the gate, and therefore the duration of bulkhead requirement and event tree for this type of failure, is the same as described for the gate trusses.

e. Scour Protection

There are three possible failure scenarios for scour protection represented by the probabilities of failure (not hazard values) in Table V.3. Probabilities of failure for each of these scenarios are assumed to remain constant throughout the analysis period. The least severe is localized damage to the scour protection and accompanied by significant scouring of dam foundation material, but not resulting in any damage to either the stilling basin or gated dam superstructure. This repair, however, does not preclude future failures of the affected section. The next severe consequence is significant scour accompanied by movement of a segment of the stilling basin. The most severe event is movement of both the stilling basin and gated dam superstructure with loss of pool. Repairs for the two most serious failures do preclude future failures. Failure of the dam superstructure resulting from undercutting is assumed to impact two gate bays. Repairs necessitated by this event would involve repair or replacement of all failed components, including the foundation material, scour protection, stilling basin, gated dam concrete and one gate. As before, this new gate would be hydraulic lift technology. The scour protection event tree is shown in Section VII.1.b.

Failure probabilities for each of the three events were calculated based on the average number of occurrences derived from the event tree. The probabilities of each type of damage depend upon the conditions shown in the event tree (i.e. operation schedule violation, high flow, or normal flow). The expected annual number of each of the three events can be calculated based on the percentages of times that the three conditions occur and the number of gate operations in a year. It was conservatively assumed that a gate operation could only scour the section immediately below it, or damage the foundation or piers only in that gate bay. The Poisson Distribution is used to determine the annual probabilities of occurrence based on the average number of each type of event expected in a typical year.

Table VI-3 Scour Protection, Stilling Basin/Apron and Gated Dam Piers
Annual Probabilities of Occurrence of Failure Events

Event	Annual Probability of Occurrence Per Gate Bay
Significant Scour	17.5%
Scour Adversely Affects Stilling Basin/Apron Stability	0.8%
Scour Affects Stilling Basin/Apron & Pier Stability	0.4%

The same pool loss duration as described for the gates would apply.

SECTION VII. ECONOMIC ANALYSIS

1. GENERAL

a. Models

The methodology to perform the economic analysis involves both simulation analysis and life cycle cost analysis. The simulation analysis was performed using a model referred to as the Life Cycle Lock Model (LCLM), while the life cycle cost analysis was performed using an Excel© workbook referred to as the Life Cycle Cost Workbook (LCCW). The two models are interrelated with the output of the LCLM being input to the LCCW as expected failure costs, for consideration with construction and O&M costs which are input separately. The models are described in detail in Appendix B, "Economic Analysis".

b. Methodology

The LCLM model estimated the expected costs due to failures of components during the analysis period for the Fix-as-Fails, Advanced Maintenance, and Deferred Maintenance alternatives, again in interactive fashion. Initial runs were made for the "fix-as-fails (FAF)" alternative, which only included repair or replacement of components after they failed. These results provide the basis against which all other alternatives are measured. The total cost of all alternatives include both Corps and non-Corps costs. Outputs of the LCLM simulations include number of failures, chamber closure durations, repair and the associated non-Corps costs. The non-Corps costs include:

- loss of navigation,
- increased pollution and damage to roads and railroads bridges due to diverted traffic,
- loss of recreation,
- loss of water supply,
- damage to bridges, and
- damage to docks.

Corps costs are determined from the appropriate engineering component event tree. Components were grouped into a system for the gates as shown in Figure VII-1. The scour protection event tree is shown in Figure VII-2. Many thousands of simulations are run for each event tree, until the results stabilize. The results were then input into the workbook and added to scheduled construction costs (zero for FAF) and O&M costs to calculate the total annual cost of this alternative. The costs were converted into present value equivalents, summed, and converted into average annual costs. This was done for each component.

Figure VII-1

Economic Model Event Tree

Inter-Related Components of Emsworth Dam

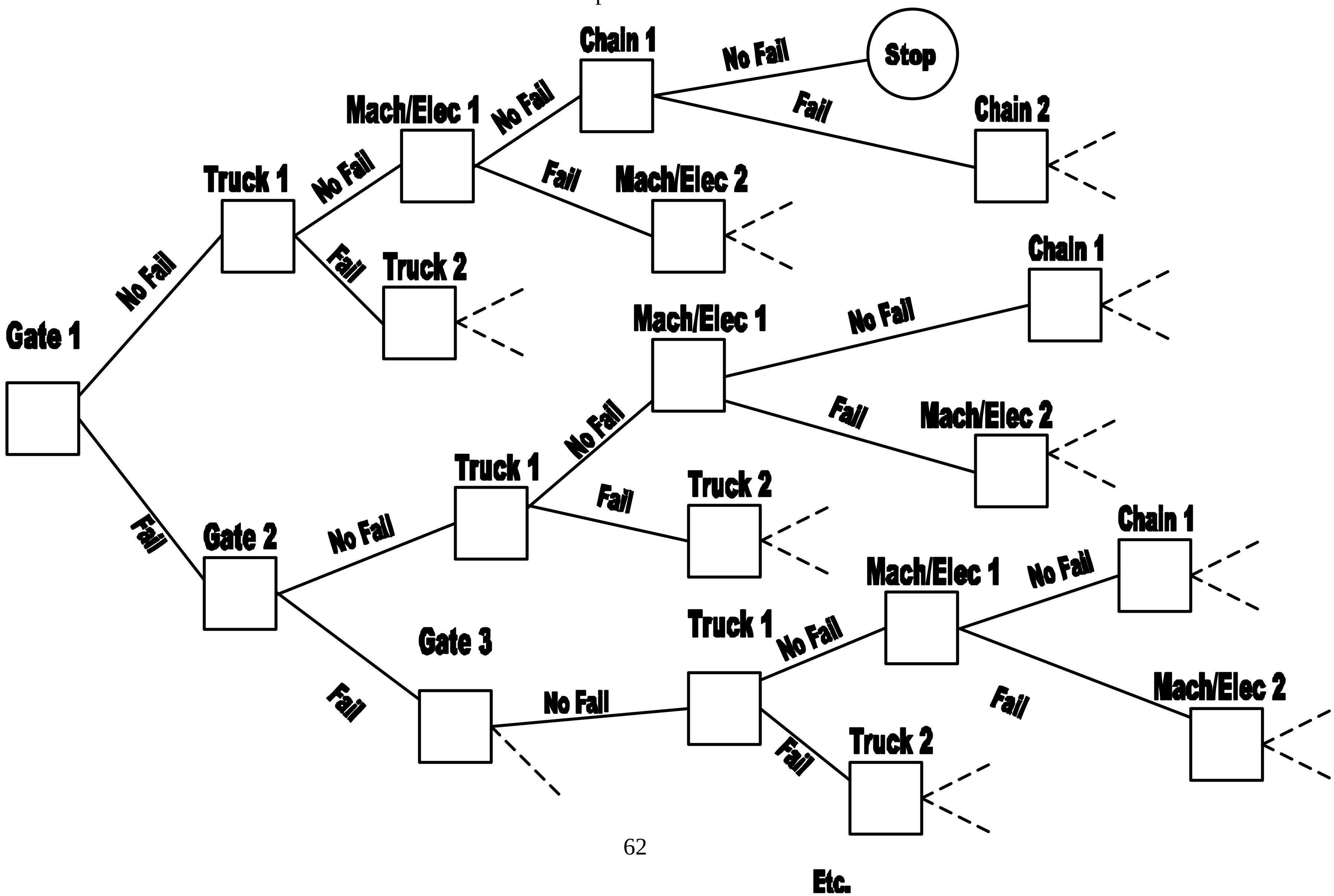

Figure VII-2
Emsworth Locks and Dams
Scour Protection Event Tree

Annual number of gate movements= 1795

Probability of Unsatisfactory Performance	Event	Probability	Event	Repair	Event Cost in Millions
0.5%	Operation Schedule Violation	94.7%	No scour or minor Scour		
		5.0%	Significant Scour	Replace Scour Protection Locally	$0.50
		0.20%	Stilling Basin Instability	Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation	$2.00
		0.10%	Instability of Stilling Basin & 2 Dam Piers	Construct Emergency Cofferdam (4 Piers), Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation, Stabilize Dams Piers	$52.50
8.0%	High Flow	98.8%	No scour or minor Scour		
		1.0%	Significant Scour	Replace Scour Protection Locally	$0.50
		0.05%	Stilling Basin Instability	Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation	$2.00
		0.20%	Instability of Stilling Basin & 2 Dam Piers	Construct Emergency Cofferdam (4 Piers), Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation, Stabilize Dams Piers	$52.50
91.5%	Normal Flow	99.9%	No scour or minor Scour		
		0.05%	Significant Scour	Replace Scour Protection Locally	$0.50
		0.002%	Stilling Basin Instability	Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation	$2.00
		0.001%	Instability of Stilling Basin & 2 Dam Piers	Construct Emergency Cofferdam (4 Piers), Replace Scour Protection, Install Sheet Piling, Tremie Concrete Stilling Basin Foundation, Stabilize Dams Piers	$52.50

Benefits of all alternatives were calculated using the FAF alternative as a baseline. By definition, the benefits of the FAF is zero. The benefits of the other alternatives reduce to the avoidance of costs arising from component failures. The FAF alternative incurs the greatest level of costs due to component failures, as would be expected. Therefore, all other alternatives have positive benefits.

The Advanced Maintenance alternative for replacement of the dam gates with hydraulic lift structures was defined as systematic replacement with O&M funds. Implementability concerns limited the replacements to occur at a frequency of one gate every two years, where the first gate replacement could occur in 2005 and the last in 2029. This alternative required the LCLM to be run for scenarios whereby there were six gates, five gates, and so on to one gate with appropriate adjustments to the other components. The results were then phased in such that the expected failure costs up to the replacement of the first gate and gate operating system was based on the existence of seven unreliable gates and systems; afterwards, the expected failure cost was adjusted downward for the existence of six unreliable gates up to the replacement of the next gate and system. The same procedure was used until all gates were replaced, after which the expected failure costs were nearly zero. Construction costs were likewise input at the appropriate years, and O&M costs were also adjusted to reflect the more efficient system. Finally, the costs were converted into present-value equivalents, summed, and converted into average annual costs. This was done for each component.

Major Rehabilitation alternatives were developed by bundling all work items into single large blocks of work. These alternatives would also include additional work to Gate #7 beyond that to be completed by 2003. The soonest that such work could be completed is 2006, with a base year of 2007 for full operations. The expected failure costs up to the year of completion of the Rehabilitation were input to the Excel workbook, and added to the cost of rehabilitation and the O&M costs to obtain the total cost of this alternative. A timing analysis was performed by adjusting the expected failure costs and re-computing the present value of construction to identify the optimum timing for repairs of each component, and for Rehabilitation as a whole.

2. EVALUATION OF ALTERNATIVES

The alternatives developed in response to the problems associated with the dams were evaluated to identify the economically preferred solution. All of the alternatives considered the reliability of three basic components: 1) gates; 2) gate operating system; and 3) scour protection. All alternatives and components were evaluated to determine the optimum timing of scheduled work. The alternatives were evaluated according to a consideration and comparison of total costs, which include: 1) construction costs; 2) O&M costs; and 3) probabilistic failure costs. The alternatives were evaluated using a 50-year project life and the FY01 discount rate of 6 3/8%.

a. Without Project Condition

EP 1130-2-500 states that the "base condition is synonymous with the without project condition. The base condition assumes that the project will be operated in the most efficient manner possible without the proposed rehabilitation". In most cases, the Without Project Condition is the fix as fails condition and, in fact, the EP seems to be based on this assumption. However, the current study identified an alternative that was more efficient than "fix as fails" and that does not involve rehabilitation. This alternative was the advanced maintenance alternative with the acquisition of an additional emergency bulkhead. The derivation of the Without Project Condition proceeded according to the following steps:

1) the "fix as fails" condition was evaluated and quantified;

2) "scheduled repairs", defined as an alternative where items are stockpiled to minimize service disruptions, was evaluated. This alternative was a small scale improvement (purchase of additional bulkhead) over the "fix as fails" alternative, that could reduce the chances of pool losses.

3) "advanced maintenance" is defined in the EP as the scheduled replacement of unreliable components over a series of years. This alternative, or some variation of it, was considered as a potential Without Project Condition because it is effective and high-side affordable using normal O&M funds.

The acquisition of an additional emergency bulkhead was analyzed with advanced maintenance to determine the cost effectiveness of this combination. The results indicated that the combination of advanced maintenance and the acquisition of the additional emergency bulkhead was the least cost (including non-Federal costs and recreation disbenefits) strategy for operating the system in the absence of rehabilitation. It was therefore designated as the Without Project Condition. Economic evaluations of the Without Project Alternatives are shown in Table VII-1.

Table VII-1 - Economics of Alternative leading to Without Project Condition
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

	Fix as Fails	Scheduled Repairs	Advance Maintenance	Without Project Condition *
1. OMRR&R Costs	**$ 5,469**	**$ 5,461**	**$ 5,329**	**$ 5,229**
Service disruptions	$ 8,795	$ 8,722	$ 4,937	$ 4,509
Reduction from FAF	$ -	$ 73	$ 3,858	$ 4,286
Benefits by Category				
Reduced disruption costs	-	$ 73	$ 3,858	$ 4,286
Avoided FAF OMRR&R costs	-	$ 5,469	$ 5,469	$ 5,469
2. Benefits	**-**	**$ 5,542**	**$ 9,327**	**$ 9,755**
Net Benefits (#2-#1)	$ (5,469)	$ 81	$ 3,998	$ 4,526
B/C ratio (#2/#1)	-	1.01	1.75	1.87

* Without is advanced maintenance with additional emergency bulkhead (Hybrid Repair/Maintenance).
OMRR&R is cost of operations, maintenance, rehabilitation, repair, and replacement.

b. With Project Condition

Rehabilitation is the only With Project Condition that was analyzed. However, rehabilitation has a timing element, which was considered. According to the EP, "immediate rehabilitation" is the undertaking of the work at the earliest possible date while "deferred rehabilitation" is the undertaking of the work at some time in the future. For the "deferred rehabilitation" alternative, rehabilitation in all possible years within the 50 year period of analysis were evaluated.

1) Immediate Rehabilitation

Immediate rehabilitation is the scheduled repair of several components during a single work effort in the immediate future. The benefits of immediate rehabilitation are minimal risk of failures and lower construction costs due to economies of scale in construction and management. As shown in the Table VII-2, some risk of failure costs remain due to the passage of several years before even the immediate rehabilitation could be accomplished. The earliest completion year is 2006; therefore, the earliest base year when the all of the benefits of the project could be realized is 2007.

The economics of immediate rehabilitation are summarized in the table below. The results indicated that immediate rehabilitation is economically justified at a b/c ration of 3.29 to 1.

Table VII-2 - Economics of Immediate Rehabilitation
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

	Immediate Rehabilitation
1. OMRR&R Costs	**$ 3,874**
Service disruptions	$ 1,525
Reduction from FAF	$ 7,270
Benefits by Category	
Reduced disruption costs	$ 7,270
Avoided FAF OMRR&R costs	$ 5,469
2. Benefits	**$ 12,739**
Net Benefits (#2-#1)	$ 8,865
B/C ratio (#2/#1)	3.25

OMRR&R is cost of operations, maintenance, rehabilitation, repair, and replacement.

2) Deferred Rehabilitation

Deferred rehabilitation is the same as immediate rehabilitation except in the timing of implementation. All 50 years in the project life were analyzed to identify the optimum timing for rehabilitation. The results below are displayed yearly up to 2010, and for each decadal point thereafter. The costs, as shown in Table VII-3, represent the sum of construction/repair costs and the costs attributable to service disruptions (pool loss). The 5,380 shown as the rehabilitation cost in 2007 is the sum of 3,874 and 1,525 shown in the preceding table. The results indicate that immediate rehabilitation is economically preferable to deferred rehabilitation (annual costs rise while benefits would only decrease).

Table VII-3 - Deferred Rehabilitation and Repairs - Average Annual Costs
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

On-Line*	Gates	Gate Operating System	Scour Protection	Total
2007	2,173	2,152	1,055	5,380
2008	2,240	2,317	1,119	5,675
2009	2,314	2,490	1,185	5,989
2010	2,388	2,658	1,242	6,288
2020	3,296	4,429	1,720	9,445
2030	4,185	5,979	1,989	12,152
2040	4,673	6,828	2,149	13,650
2050	4,784	7,060	2,238	14,083

* work performed in four preceding years. ex. 2007 base year meant rehab work performed in 2003-2006.

c. Economically Preferred Alternative

The analysis indicated that the optimum Without Project Condition is advanced maintenance plus an additional emergency bulkhead. Basically, this alternative involves replacing the unreliable components using normal O&M funds, and using the additional emergency bulkhead to reduce the impacts of failures.

The analysis also indicated that the optimum "with" project condition is immediate rehabilitation, with completion in 2006.

The optimum With and Without project conditions were compared to identify the economically preferred alternative.

A comparison of the With and Without costs attributable to service disruptions is provided in Table VII-4. The cost are 66 percent lower for the "with" alternative.

Table VII-4 - Costs of Disruption - With and Without Conditions
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

Impact Category	Without Project Condition *	Rehab 03-06 **	Reduction due to Rehab
Commercial Transportation Costs	$ 3,758	$ 1,272	$ 2,486
Pollution	$ 458	$ 155	$ 303
Rec Boating Losses	$ 13	$ 4	$ 9
Water Supply Losses	$ 113	$ 38	$ 75
Roads/Railroads Repair Costs	$ 10	$ 3	$ 7
Bridges Repair Costs	$ 144	$ 49	$ 95
Docks Repair Costs	$ 13	$ 4	$ 9
Total Impacts	$ 4,509	$ 1,525	$ 2,984

* Advanced maintenance with additional emergency bulkhead
** Base year of 2007

The total OMRR&R costs of the dams under the Without and "immediate rehabilitation" alternatives are listed in Table VII-5. The immediate rehabilitation costs of unscheduled repair costs are significantly lower, the scheduled repair costs are slightly higher, and the normal O&M costs are lower than for the Without Project Condition. Overall, the costs of immediate rehabilitation are twenty-five percent lower than for the Without Project Condition.

Table VII-5 - OMRR&R Costs of With and Without Project Alternatives
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

	Without Project Condition *	Rehab 03-06 **	Reduction due to Rehabilitation
Unscheduled Repairs	$ 2,682	$ 908	$ 1,774
Scheduled Repairs	$ 2,440	$ 2,946	$ (506)
Oper & Maintenance	$ 107	$ 20	$ 87
Total OMRR&R	$ 5,229	$ 3,874	$ 1,355

* Without is advanced maintenance with additional emergency bulkhead.
** Base year of 2007
OMRR&R is cost of operations, maintenance, rehabilitation, repair, and replacement.

A comparison of the economics of the With and Without Project Conditions is provided in Table VII-6. The With is superior to the Without in terms of both costs (lower) and benefits (higher).

Table VII-6 - Economics of With and Without Project Conditions
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values

	Without Project Condition	Immediate Rehabilitation
1. OMRR&R Costs	**$ 5,229**	**$ 3,874**
Service disruptions	$ 4,509	$ 1,525
Reduction from FAF	$ 4,286	$ 7,270
Benefits by Category		
Reduced disruption costs	$ 4,286	$ 7,270
Avoided FAF OMRR&R costs	$ 5,469	$ 5,469
2. Benefits	**$ 9,755**	**$ 12,739**
Net Benefits (#2-#1)	$ 4,526	$ 8,865
B/C ratio (#2/#1)	1.87	3.25

* Without is advanced maintenance with additional emergency bulkhead.
With is immediate rehabilitation.
OMRR&R is cost of operations, maintenance, rehabilitation, repair, and replacement.

d. Summary Table

A summary table showing the economics of all alternatives is provided in able VII-7.

Table VII-7 - Economics of All Alternatives
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

Impact Category	Fix as Fails	Scheduled Repairs	Advance Maintenance	Scheduled Replacemt w/ addit emerg bulkhead*	Rehab 03-06
Commercial Transportation Costs	$ 7,330	$ 7,269	$ 4,115	$ 3,758	$ 1,272
Pollution	$ 893	$ 886	$ 501	$ 458	$ 155
Rec Boating Losses	$ 25	$ 25	$ 14	$ 13	$ 4
Water Supply Losses	$ 221	$ 219	$ 124	$ 113	$ 38
Roads/Railroads Repair Costs	$ 19	$ 19	$ 11	$ 10	$ 3
Bridges Repair Costs	$ 281	$ 278	$ 158	$ 144	$ 49
Docks Repair Costs	$ 26	$ 26	$ 14	$ 13	$ 4
Costs for Maintaining WOP	$ 5,469	$ -	$ -	$ -	$ -
Total Impacts by Alternative	$ 14,264	$ 8,722	$ 4,937	$ 4,509	$ 1,525
Total Impacts under the WOPC	$ 14,264	$ 14,264	$ 14,264	$ 14,264	$ 14,264
Benefits by Alternative	$ -	$ 5,542	$ 9,327	$ 9,755	$ 12,739
Total AAC by Alternative	$ 5,469	$ 5,461	$ 5,329	$ 5,229	$ 3,874
Net Benefits by Alternative	$ (5,469)	$ 81	$ 3,998	$ 4,526	$ 8,865
BCR by Alternative	0.00	1.01	1.75	1.87	3.29

* Without Project

3. INCREMENTAL AND TIMING ANALYSIS

Cost are categorized as scheduled repair costs, unscheduled repair costs, and the costs of opportunities foregone due to disruptions in service. Benefits are counted as the retention of these otherwise "foregone" opportunities.

a. Incremental Justification of Each Component

Individual component repairs are considered economically justified if the "cost" (repair plus disbenefits) of the repairs is less than the cost of alternative courses of action. As shown in the table, the immediate repair cost is lower than the costs of the alternatives for all three components. Therefore, immediate repairs of the components are incrementally justified.

Table VII-8 - Incremental Analysis
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

	Both Dams				
	Fix as Fail	Sched. Repairs	Advance Maint.	Without Condition	Immediate Repairs
Gates	4,726	4,835	3,688	3,569	2,173
Gate Op	7,285	7,216	4,900	4,491	2,152
Scour	2,252	2,252	1,571	1,571	1,055
Total	14,263	14,303	10,159	9,631	5,380

b. Timing Analysis for Deferred Repairs

The optimum year to perform the work is the year in which the "costs" are lowest. As shown in Table VII-9, the year of "lowest" cost is 2007. Delaying repairs beyond this year adds to the costs, particularly the risk of failure costs.

Table VII-9 - Deferred Repairs
(thousands of dollars; Mar 01$; 6 3/8%; 50 years; average annual values)

On-Line*	Gates	Gate Operating System	Scour Protection
2007	2,173	2,152	1,055
2008	2,240	2,317	1,119
2009	2,314	2,490	1,185
2010	2,388	2,658	1,242
2020	3,296	4,429	1,720
2030	4,185	5,979	1,989
2040	4,673	6,828	2,149
2050	4,784	7,060	2,238

4. SCREENING AND FINAL BENEFITS AND COSTS

The analysis was performed using screening level cost estimates while the detailed M-CACES estimates were under development. The M-CACES became available as the report neared completion. The preliminary costs, the M-CACES costs without contingencies, and the M-CACES costs with contingencies were compared to ensure that there were no significant biases in the analysis. The comparison shows that the M-CACES without contingencies is 8 percent higher and the M-CACES with contingencies are 23 percent higher than the preliminary costs used in the analysis. While the latter percentage is high, the discrepancy is not biased towards any one component. Therefore, the results based on the preliminary costs are considered valid.

Table VII-10 - Comparison of Preliminary and M-CACES Costs
(Thousands of dollars; Mar 01 price level)

	Preliminary	M-CACES w/o contin.	M-CACES with contn.
1. Gates	$ 24,000	$ 23,100	$ 26,957
2. Gate Operating System	17,000	17,400	20,305
3. Scour Protection	11,500	12,500	14,587
4. Miscellaneous support items	0	3,900	4,551
5. Total	$ 52,500	$ 56,900	$ 66,400

Both the preliminary and M-CACES costs were used for comparison with the project benefits and to computed the traditional economic table displaying the results, as shown in the Table VII-11.

Table VII-11 - Annualized Costs and Benefits
(Thousands of Dollars; Mar 01 price level)

	Preliminary	M-CACES w/o contin.	M-CACES with contin.
1. Construction	$ 52,500	$ 56,900	$ 66,400
2. Interest during Construction (0.06375 x (3 yrs/2) x # 1)	5,020	5,441	6,350
3. Total Investment (#2 + # 3)	57,520	62,341	72,750
4. Annualized Cost (0.066789 x # 3)	3,842	4,164	4,859
5. Operation and Maintenance	20	20	20
6. Total 0MRR&R Costs (# 4 + # 5)	3,862	4,184	4,879
7. System Disruption Costs	7,269	7,269	7,269
8. Avoided FAF Repair Costs	5,469	5,469	5,469
9. Total Benefits (#7 + #8)	12,738	12,738	12,738
11. Net Benefits (# 9 - # 6)	8,876	8,554	7,859

12. B/C ratio (#9 / #6)	3.3	3.0	2.6

Note: the preliminary costs in above table do not include risk of failure costs that were included in numbers previously. This is the principle reason for the slight difference in benefits and costs between the above and the numbers shown earlier in the report.

Tests were conducted to measure the sensitivity of the results to the discount rate, growth in disbenefits over time, probabilities of failure, and the generalization of the probability of one item to the whole family of items. The results indicate that "Immediate Rehabilitation" remains the NED plan under all reasonable variations in the above values. A detailed description of the sensitivity tests and the results of the tests is provided in Addendum 10.

SECTION VIII. OTHER CONSIDERATIONS

1. COMPONENTS NOT ANALYZED WITH RELIABILITY

a. Service Bridges

Potential loss of a service bridge would result in unavailability of the bulkhead crane, which is used to service the gates and to install the emergency bulkheads. Should such an event take place, such as a significant pier movement resulting in lateral movement of bridge seats, bearings and hence the main girders, the bulkhead crane could not safely be used necessitating that such work be done from a barge-mounted crane. This work becomes more difficult as a barge-mounted crane cannot lift from directly above the load point. Repairs to the service bridge could take from several weeks to several months depending on the nature of the repairs. The major impact would be a gate failure and with the service bridge out of commission, the bulkheads could not be installed. This could create a situation where there would be a loss of pool for up to 45 days while a cofferdam or dumped rock was installed upstream of the gate. This work is recommended to occur with the other work during the Immediate Rehabilitation.

b. Dam Concrete

While the concrete in the dam piers is generally in fair condition, it shows advanced deterioration in localized areas, particularly on the pier decks (top horizontal surfaces) -- beneath the bearings supporting the hoisting machinery beams and in the areas near the top of the piers on the downstream side. The bridge deck concrete shows signs of scaling at the top and low areas where water can pond; localized spalled areas occur at the underside of the slabs with fine cracks. The bulkhead storage pit concrete is in fair condition except for small areas of deterioration in the main channel dam; however, the similar pit in the back-channel dam is in very poor condition, with critical areas such as runaway support piers badly deteriorated. The dam abutment in the main channel is in fair condition, while the Neville Island abutment of the back channel dam is seriously deteriorated, with major structural cracks.

The concrete in the dam's gate sills and piers is generally in fair to good condition, with only limited areas near the top of several piers showing signs of deterioration. However, the concrete of the dam abutments and bulkhead storage pits, particularly in the back channel dam, is in very poor condition with severe deterioration, cracks, and spalled areas.

Deterioration of concrete is an ongoing process. As the process continues, water infiltrates the pores of the concrete where it can dissolve the cement matrix surrounding the aggregate, and can freeze and expand, cracking the concrete. As this process continues, more area is made available for water infiltration and less good concrete remains. At some point, the concrete is not capable of carrying the loads it was designed for. This can be critical in areas such as gate anchorages, where a failure would be catastrophic.

Concrete work is recommended to occur with the other work during the Immediate Rehabilitation for the following reasons: Removal and replacement of the deteriorated deck and other areas prior to replacement of the machinery houses, machinery and supporting beams recommended as part of the Major Rehabilitation would avoid significant outage time and expense. Once the new machinery is installed and operational, any concrete repair work required beneath these areas would necessitate a second outage for two gate bays since each pier supports the hoisting equipment for one-half of a gate bay on the left and right side of the pier. Not only would this pier (one-half of two gate bays) become inoperable for the construction time required to remove the new equipment, remove the deteriorated concrete areas, replace the concrete and replace the hoisting machinery but the additional expense for the second contract would have to be programmed.

2. ENVIRONMENTAL AND CULTURAL RESOURCE CONSIDERATIONS

Environmental and Cultural Resource impacts of the Without Project Condition and Rehabilitation alternatives are not significant and therefore are not a major factor in selection of the recommended plan. The only environmental impact noted in the Environmental Assessment (EA) for any of the alternatives relates to the temporary impacts due to Rehabilitation activities, including land disturbances associated with construction lay-down areas. As suggested by the EA, the temporary impacts related to each type of alternative are minor. There are Cultural Resource impacts associated with either type of alternative associated with replacement of the gates, as even in the Without Project Condition it is not realistic to expect that the existing gates could survive another 50 years. For either alternative, Cultural Resource impacts are mitigatable as described in the EA.

The major beneficial impact of an immediate Major Rehabilitation alternative is the highest degree of assurance possible of no pool loss associated with failure of dam gate components. This assurance can not be made with any of the other alternatives that either do not include or defer Major Rehabilitation. In addition to adverse economic impacts as described in prior sub-sections, pool loss would also result in some undetermined adverse environmental impacts due to lower river elevations and exposed banks. Such impacts would be totally avoided with the Immediate Rehabilitation alternative. Furthermore, there would not be any impacts to navigation due to any rehabilitation activities.

The only adverse impacts on the aquatic environment due to replacement of gates or scour protection include slight increases in turbidity, the release of any pollutants contained in disturbed benthos and the temporary disruption of fish and benthic populations in the area of scour protection placement. These effects will be both minor in nature and short in duration. After the scour protection is replaced, fish and benthic organisms will repopulate the disturbed area and turbidity will settle out. As the benthos is composed of primarily rock and gravel at the dam apron, replacement of the apron riprap will result in virtually no release of fines or sediments. These impacts could also be incurred in the Without Project Condition alternatives, albeit unpredictable in timing, due to gate or scour protection replacement due to component failure. It must also be noted that there is a chance that these impacts could be much more severe in the Without Project Condition alternative if portions of the stilling basin and gated dam superstructure fail, since the construction activities to repair those failures would be quite significant.

Furthermore, there is a chance that the existing rock-blanket scour protection that would be replaced in the Rehabilitation plans would be relocated just downstream to improve the tailwater fishery habitat. Therefore, the difference in environmental impacts between the Without and Major Rehabilitation alternatives could either be a net positive for the Rehabilitation plans, or at the worst, considered virtually the same.

In summary, the net environmental and cultural resource impacts probably favor Major Rehabilitation alternatives slightly over the Without Project Condition due to avoidance or a lessened likelihood of pool loss and possibly the need to reconstruct portions of the stilling basin/apron and gated dam superstructure.

3. REAL ESTATE CONSIDERATIONS

The Ohio River (River) is a navigable river and the United States enjoys navigational servitude within the River and up to the Ordinary High Water Line (OHWL) on both banks of the main channel of the River and the "back channel". Emsworth Locks and Dams is located entirely within the State of Pennsylvania. Currently, two (2) license agreements are in place for a parking area, a railroad crossing, a pedestrian tunnel under the railroad and for a sewer line. The land is owned by Norfolk Southern Railroad. These licensed areas are critical for the continued operation and maintenance of the Emsworth facility. Should these license agreements be canceled by the landowner, the Emsworth facility would be adversely effected due to lack of access, parking for employees and sanitary facilities. As part of the rehabilitation project, it is preferable to obtain permanent real estate interests over these license areas in the form of a permanent easement. This action would insure that the United States would maintain unimpeded access to the Emsworth facility and would eliminate yearly license fees and the associated administrative costs relative to these license agreements.

Two (2) additional license agreements are in place for the left bank . Permanent real estate interests for the areas covered under these license agreements are not being sought as part of the Rehabilitation Report but will be pursued at a later time if additional work is proposed on the abutment.

Converting the license agreements on the right bank to permanent real estate interests were not addressed in the Real Estate Plan at Appendix G. During the QC review of the Real Estate Plan and after consultation with Operations and Readiness, it was decided that permanent real estate interests would be preferable to license agreements on the right bank. It is proposed to prepare and submit a supplemental Real Estate Plan that will address the right bank license agreements subsequent to approval of the RER. The estimated additional costs associated with the Supplemental Real Estate Plan and proposed acquisition are $43,500.

.

Emergency repairs inherent in all of the alternatives summarized in Table V-3, that are not conducted as part of an immediate rehabilitation project, would likely require the same real estate interests identified in Appendix G of the report.

Immediate negotiations with the landowners would be necessary to acquire sufficient real estate rights to permit repairs under emergency conditions. Successful negotiations will depend entirely upon a willing landowner.

SECTION IX. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The conclusion of the analysis is that Immediate Rehabilitation is the preferred solution in almost all of the major areas of consideration. Immediate rehabilitation is the economically preferred (NED) plan and, rather uniquely, it requires less expenditure of Government funds than the alternatives. Environmentally, it is neutral to slightly preferred compared to the alternatives. The same is true of the other categories. Table IX-1 presents a summary comparison of six evaluated alternatives according to the full range of decision making criteria.. As a representative scheduled rehabilitation plan, the plan with completion by 2017 was selected for inclusion in the table. Immediate rehabilitation was more economical than all of the scheduled rehabilitation alternatives.

Immediate Rehabilitation includes immediate installation of 13 new hydraulic lift gates. The on-going study of larger locks on the Upper Ohio River alluded to previously could result in a recommendation for a new 110' wide riverward lock at Emsworth, which would necessitate removal of the first gate bay. Construction of a wider (and longer) river lock at Emsworth would most certainly follow the proposed rehabilitation work. In effect, this would mean that the new hydraulic gate in gate bay #1 would be removed very early in its design life. The District does not feel that that possibility should preclude a new gate for gate bay #1, as even if the "worst" occurs and this gate must be removed, it could be salvaged and used for maintenance of the other gates.

Immediate rehabilitation also includes significant reconstruction of downstream scour protection. As designed, the scour protection may not be compatible with a lock improvement plan that results in a lower downstream pool level. Plans are to model this situation prior to construction, by which time the likely lock improvement plan may be better known.

Table IX-1 Summary Analysis of Plans
(Sheet 1 of 3)
Emsworth Dams

Item	Fix-As-Fails (FAF)	Scheduled Repairs	Advanced Maintenance	Without Project Condition	Immediate Rehabilitation	Scheduled Rehabilitation 2017
1. Alternative Description	Replace Gate #7 with hydraulic lift gate as scheduled (2002), repair or replace all other dam components only after failure.	Same as FAF, except that an extra bulkhead is constructed and stored to serve both the main and back channel dams.	Save as FAF, except that gates are replaced every two years, beginning in 2006, and scour protection is replaced every 15 years beginning in 2007.	Combines features of Scheduled Repairs and Advanced Maintenance scenarios.	Replace 13 gates with hydraulic lift gates from 2003-6, replace scour protection for both dams from 2003-7. No chance for pool loss after rehabilitation work.	Similar to Immediate Rehabilitation, except that rehabilitation of gates is deferred until 2016 and scour protection is completed in 2017.
2. Construction Costs (Screening) $ thousands (Not Discounted)	*Scheduled* 0 *Unscheduled* 60,900 *Total* 60,900	2,000 57,700 59,700	65,500 10,900 76,400	67,500 10,500 78,000	52,500 1,400 53,900	52,500 4,200 56,700
3. National Economic Development a. Summary of Annual Benefits and Costs	*Benefits:* 0 *Costs:* 5,469 *Net Benefits:* (5,469) *B/C Ratio* 0.0	5,542 5,461 82 1.01	9,328 5,329 3,998 1,75	9,756 5,229 4,527 1.87	12,740 3,874 8,866 3.29	9,922 4,191 5,731 2.37
3.b. Incremental Net Benefits Over Without (thousands)	(9,966)	(4,455)	(528)	-	4,339	1,204
3.c Annual Benefits (Avoided Losses)	*Commercial Navigation* - *Externalities* - *Recreation* - *Water Supply* - *Roads/ Railroads* - *Bridge Piers* *Decks* - *Docks* - Avoided FAF OMRR&R (5,469) Totals 0	 61 7 0 0 0 3 0 5,469 5,542	 3,215 392 11 97 8 123 12 5,469 9,328	 3,572 435 12 108 9 137 13 5,469 9,756	 6,058 738 21 183 16 232 22 5,469 12,740	 3,712 452 13 112 9 142 13 5,469 9,922

TABLE IX-1. Summary Analysis of Plans (Sheet 2 of 3)
Emsworth Dams

Item	Fix-As-Fails (FAF)		Scheduled Repairs	Advanced Maintenance	Without Project Condition	Immediate Rehabilitation	Scheduled Rehabilitation 2017
3.d. Annual Costs	*Scheduled Construction*	0	36	2,285	2,240	2.946	1,588
	Unscheduled Construction	5,232	5,188	2,937	2,682	908	2.583
	O&M	237	237	107	107	20	20
	Total	5,469	5,461	5,329	5,229	3,874	4,191
4. Environmental Impacts	*Wetland / Riparian:* Degraded During Pool Losses		Degraded During Pool Losses	Degraded During Pool Losses	Degraded During Pool Losses	No Impact	Degraded During Pool Losses
	b. Aquatic Habitat: Minimal Temporary Impacts During Work Activities		Minimal Temporary Impacts During Work Activities	Minimal Temporary Impacts During Work Activities	Minimal Temporary Impacts During Work Activities	Minimal Temporary Impacts During work Activities	Minimal Impacts During Work Activities
	c. Terrestrial Habitat: No Impact		No Impact	No Impact	No Impact	Minimal Temporary Impact to Laydown area. Designated trees for Indiana Bat habitat will not be removed.	No Impact
	d. Endangered Species No Impact		No Impact	No Impact	No Impact	No Impacts	No Impact
5. Cultural Resources	No Impact (Only if all gates are replaced, then mitigation required)		No Impact (Only if all gates are replaced, then mitigation required)	All onsite impacts fully mitigated	All onsite impacts fully mitigated	All onsite impacts fully mitigated	All onsite impacts fully mitigated
6. Real Estate Impacts	6.19 Acres Temporary Easements, Acquired Under Emergency Condition (due to any gate failure)		6.19 Acres Temporary Easements, Acquired Under Emergency Conditions (due to any gate failure)	6.19 Acres Temporary Easements, Acquired Under Emergency Conditions (due to any gate failure)	6.19 Acres Temporary Easements, Acquired Under Emergency Conditions (due to any gate failure)	6.19 Acres Temporary Easements, Acquired Under non-Emergency Conditions (due to any gate failure)	6.19 acres temporary easements, acquired under emergency & non-emergency conditions (due to any gate failure)

TABLE IX-1. Summary Analysis of Plans (Sheet 3 of 3)
Emsworth Dams

Item	Fix-As-Fails (FAF)	Scheduled Repairs	Advanced Maintenance	Without Project Condition	Immediate Rehabilitation	Scheduled Rehabilitation 2017
7. Social Impacts	Major disruptions during pool losses.	Major disruptions during pool losses	Major disruptions during pool losses	Major disruptions during pool losses	No Impact.	Major disruptions during pool losses.
8. Plan Evaluation a. Ensure Safe & Reliable Dam Functions?	No	No	Partial	Partial	Yes	Partial
8.b. Response To Evaluation Criteria:	*Completeness:* Yes *Effectiveness* Rank 6th *Efficiency:* Rank 6th *Acceptability:*Rank 6th	Yes 5t 5th 5th	Yes 3rd 4th 4th	Yes 2nd 3rd 3rd	Yes 1st 1st 1st	Yes 4th 2nd 2nd
Recommended Plan - Traffic Accommodated					*(million tons)* *2010* - 28.5 *2030* - 32.1 *2050* - 35.6	
Recommended Plan - MCACES Costs				March 2001; $ 000's 1. Construction 2. IDC (6 3/8%; 3 yrs) 3. Subtotal 4. Ave Ann. 5. O&M 6. Total Ave Cost 7. Total Benefits 8. Net Benefits 9. B/C ratio	 $66,400 6,350 72,750 4,859 20 4,879 12,738 7,859 2.6	

2. RECOMMENDATION

It is recommended that the immediate rehabilitation of the Emsworth Dams be approved and funded at a current cost of $66,400,000. Included as part of the rehabilitation are the installation of thirteen new dam gates; thirteen sets of hydraulically operated gate hoisting systems; electrical power and distribution system; scour protection system; repairs to the service bridge, concrete repairs to the gate bays, repairs to the steel bearing devices supporting the main girders; replacement of the locomotive crane rails; replacement of the machinery support beams, bearings and machinery houses; and other miscellaneous/small cost items that are necessary for reliable operation and/or safety reasons.

3. MAJOR REHABILITATION CLASSIFICATION

The recommended plan resulting from this Major Rehabilitation Evaluation of Emsworth Dams includes replacement of dam gates, repair of scour protection and damaged concrete on dam the dam piers, and replacement of concrete slabs, repair of rail components, and some repainting of girders on the service bridge. The gate replacement and scour protection repairs meet the requirements of reliability rehabilitation classification as described in EP 1130-2-500. Pier concrete repairs should also be made to supplement replacement of gate components. Service bridge work is essential to maintaining access to gate machinery and ensuring that bulkhead cranes are available when needed. All work is therefore recommended for implementation.

4. DESCRIPTION OF RECOMMENDED WORK

a. Project Features

1) Dam Lift Gates

The existing riveted steel lift gates will be replaced with redesigned steel gates of welded construction. The new gates are designed in accordance with EM 1110-2-2701 and include barge impact loads. The new lift gate consists of an upstream skin plate supported by top and bottom trusses and cross-bracing composed of wide-flange members. At each end of the gate is a truck assembly which houses a pair of track wheels on the downstream side which bear against the dam piers during normal operation. For detailed drawings of the new gates, see Appendix A, section A.6. Due to the size of the gates (106'-10" long and approx. 75 tons) we anticipate the gates will be fabricated in sections, transported to the site and assembled in-place on the dam gate sills. Prior to removing an existing gate the maintenance bulkhead units will be set in the gate bay and remain there until the new gate is installed and operational. Since there is one set of bulkheads for the main channel dam and one set for the back channel dam, work on one gate on each dam will proceed simultaneously. There are eight (8) gates on the main channel dam and 6 gates on the back channel dam for a total of 14 gates. There is currently a contract in place using Operations and Maintenance funding to replace one of the main channel gates (Gate #7). The work recommended by this report includes replacement of the remaining 13 gates.

2) Dam Lift Gate Operating Machinery

The existing gate lifting system (roller chains and hoisting machinery at each end of the gate) will be replaced by two hydraulic cylinders that provide a total vertical travel of 40 feet. This innovative hydraulic cylinder system raises itself in two stages, cutting the required stroke to lift the gates from 40 feet to 20 feet. The cylinder body has two trunnions, one at each end of the body, connected together by guide rails. Hydraulically operated trunnion pins are retracted to disengage one trunnion, allowing the cylinder body to travel on the guide rails to the trunnion on the opposite end. The pins are then extended to engage that trunnion. Hydraulically operated dogging beams will be installed at the mid-point of gate travel (20 feet). For daily operations the cylinder normally hangs from the upper (rear) trunnion, allowing gate operations from 0 feet to 20 feet open. During a major flood event the gates are fully raised to 40 feet where they are hung from dogging hooks. To do this, the gate is first raised 20 feet and supported by the new dogging beams. The trunnion pins are then disengaged from the upper trunnion and the cylinder is extended to raise the cylinder body until the trunnion pins are lined up with the lower trunnion. The lower trunnion is then engaged and the gate is fully raised to the dogging hooks. The complete operation can be programmed to raise the gate automatically from 0 feet to 40 feet as if it were a single stage lift. The two hoist cylinders are synchronized electronically by sensing rod position to insure precise leveling and positioning of the new gates. This system will provide reliable remote operation from the operations building on the lock and greatly reduce the required maintenance.

Installation of the new system will include minor concrete removal and replacement and modifications to the existing machinery buildings.

3) Scour Protection

The recommended solution presented in this report to address the continual scour problem at the Emsworth Dams is a stilling basin extension. First, the existing stone protection would be removed, and a cut-off wall would be placed to prevent voids from developing under the stilling basin/apron due to piping of material. Then, the extension could be constructed consisting of layers of graded stone capped with 4 feet of concrete. The cap would be offset several feet below the top of apron and would extend about 70 feet out. A portion will be sloped to allow for flow expansion and partial dissipation of high velocity jets leaving the apron, while protecting the cut off wall. Immediately downstream of the concrete, another cut-off wall would be placed. Stone protection would continue for approximately 80 feet until it ties into the natural bedrock bottom, sealing in the under lying material. Unfortunately, it cannot be determined analytically how effective the offset and slope of the extension will be in reducing velocities without a model study. In addition, it is possible that a model study would suggest a different configuration. The chosen plan would also allow abnormal operations to be made without fear of causing damage, recognizing that such operations are frequently needed to pass ice and debris, when gates are out of service, or as the result of accidents. We believe that a comprehensive physical model will allow an intensive study and permanent solution of the problem and will return benefits many times the cost.

4) Service Bridge Deck

Each of the 14 bridge spans (8 on the main channel dam and 6 on the back channel dam) has a concrete deck slab 6” thick by 8’-0” wide by 102’-6” long with intermediate control joints. These existing slabs will be removed and replaced in-kind with a new reinforced concrete deck slab.

5) Crane Rail System

All rusted and deteriorated components, including rail plates, rail clips, splice bars and track bolts, will be replaced.

6) Steel Bridge Members

To protect the bridge superstructure from deterioration, main girders and cross-bracing will be cleaned and the surfaces coated with an appropriate paint system. In connection with this work, the conduit trays which carry the electrical conduits across the bridge and have already corroded away in many places will be replaced.

b. Timing

The earliest probable scenario of accomplishing this recommended work is that funds will be available at the beginning of Fiscal Year 2003. The initial effort will involve design work and the production of plans and specification for three contracts. The first contract will be for painting the service bridge with an award in March 2004. The painting will take place over the next three painting seasons (May – November) and be completed by November 2006. The second contract will be for the dam gates and machinery and will be awarded in February 2005. Three construction seasons will be required for this work with a scheduled completion in August 2008. The third contract for the scour protection will also be awarded in February 2005 with a scheduled completion date of October 2007.

The conclusion of this evaluation is that the recommended plan be carried out at the earliest time possible. It is stressed that a sense of urgency accompanies this conclusion, given the demonstrated probability of unsatisfactory performance of these components.

c. Real Estate

The only lands that need to be acquired for the recommended Major Rehabilitation project are the Temporary Work Area Easements, shown as Tract No’s. 101E & 100E-3 outlined in blue on Exhibit A of the Appendix G. These two tracts were previously acquired as part of the rehabilitation project that was constructed in the early 1980’s. Additional fee lands were also acquired under that authorization to purify title to lands that were being occupied by the Government but were never acquired. All title related issues were addressed during the last rehab. Project, so no additional lands need to be acquired now.

No Public Law 91-646 relocations are included in the acquisition program.

The total cost to acquire these temporary easements is estimated to be $65,344.

d. Federal Interest

This Major Rehabilitation Evaluation Report has been conducted as a result of a very high degree of concern for the corroded gate truss members and failing truck assemblies, outdated mechanical and electrical gate operating machinery, deteriorated concrete in dam piers and service bridge slabs, and the potential for scour of foundation material for the stilling basin and dam apron that could result in failure of gate piers, stilling basin or dam apron. Numerous problems associated with operating the old chain hoist gates are well documented and have resulted in the requirement that all gate operations be observed by lock staff to lessen the chances for catastrophic damage even under normal operating conditions. Failure of dam gates or dam piers could result in loss of Emsworth pool. The work recommended herein is viewed as mandatory to keep the risk of loss of Emsworth pool to acceptable levels. The Federal Interest is in insuring the continued safe operation of this Federal project and the protection of commercial navigation and shoreside facilities that depend upon a stable Emsworth pool. Doing so is in the best interest of the general public.

SECTION X. ADMINISTRATIVE CONSIDERATIONS

1. PROJECT COST ESTIMATE

The recommended plan involves replacement of all gates and hoist equipment with hydraulic lift structures and machinery, removal and reconstruction of scour protection immediately downstream of the stilling basin/apron of both dams, restoration of service bridge infrastructure and spot repairs of dam concrete. The estimated M-CACES cost expressed at March 2001 price levels is $66,400,000. The fully funded cost estimate, based on completion of construction in 2007, is $78,260,000.

2. PROJECT COST SHARING

Under the provisions of the Water Resource Development Act of 1986, construction of Major Rehabilitation projects is funded 50 percent Federal and 50 percent by the Inland Waterways Trust Fund.

3. PROJECT MANAGEMENT PLAN

A Project Management Plan (PMP) was prepared for the proposed work items and is contained in Appendix E. This plan includes the proposed schedule for all work and corresponding annual funding requirements.

4. EFFORTS DURING PRECONSTRUCTION ENGINEERING AND DESIGN

Much of the design work for installation of the gates has already been accomplished as part of the current effort to replace Gate #7. This work is reflected in the engineering drawings of the new gates, which appear in Appendix A. All remaining design work needed to complete the recommended plan will be performed during the pre-construction engineering and design (PED) phase of the project as described in the PMP.